Marshall Miller & Associates, Inc.

Energy & Mineral Resources

Environmental Science & Energy

Oil & Gas Division

Coalbed Methane
Completion and Production Optimization

Presented to:
Midcontinent Coalbed Methane Symposium
Tulsa, Oklahoma

Presented by:
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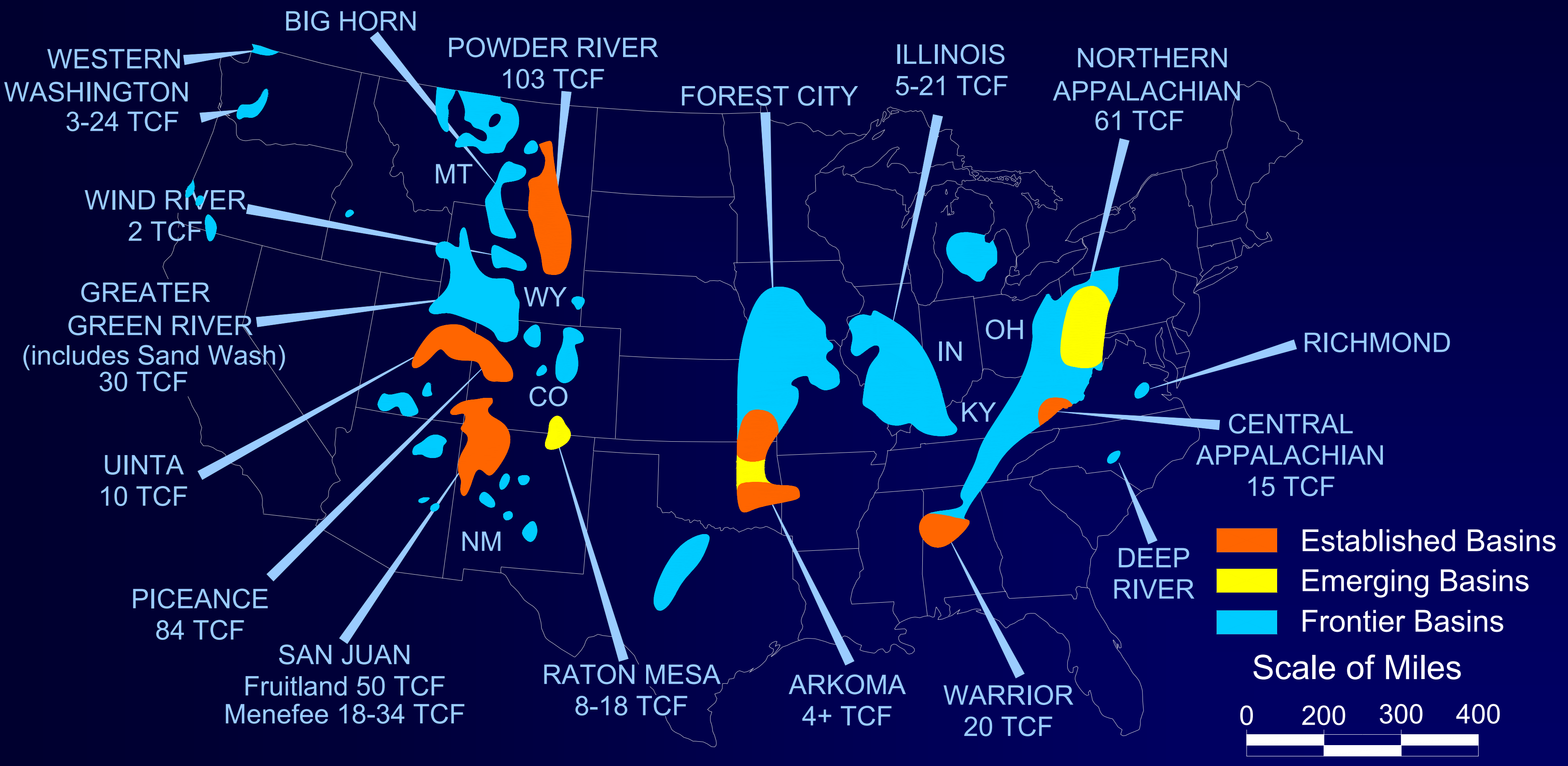
US Coalbed CBM Resources



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CBM Overview

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Factors that Govern Project Success

- Gas in-place
  - Coal thickness
  - Gas content
- Permeability
- Pipeline access
- Gas price
- Cost control

Coal Thickness – Geophysical Logs

- Bulk density < 2 gm/cc
- High resolution presentation:

  100 feet: 25 inches vs 5 inches

- Clean gamma ray < 75 API units
- Note adjacent formations

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Gas Content - Cores

- Continuous coring rig
- Desorption testing
- Offset core data
- Cores have other value

Gas In-Place

- Some operators only complete coal seams greater than one-foot thick
- Little evidence of significant gas from thinner coals
- Perforating and fracture initiation problems in thin seams
- High-resolution open-hole and cased-hole logs

Permeability

- Without permeability, gas-in-place is not a producible reserve
- Structure governs permeability
- Structural deformation, especially anticlines, enhance permeability apparently by opening cleats
- Mapped peak production usually overlays mapped structural features very closely

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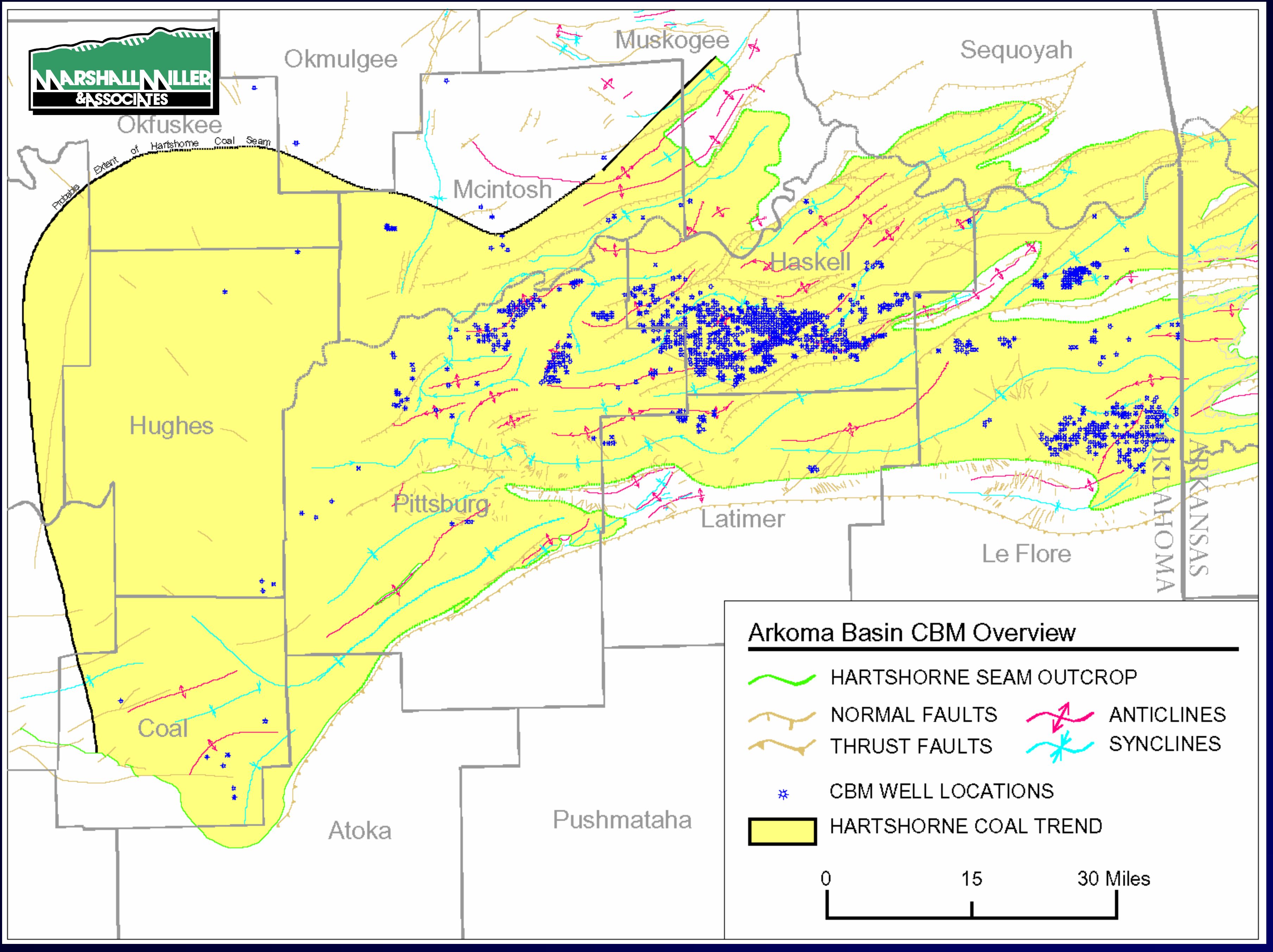
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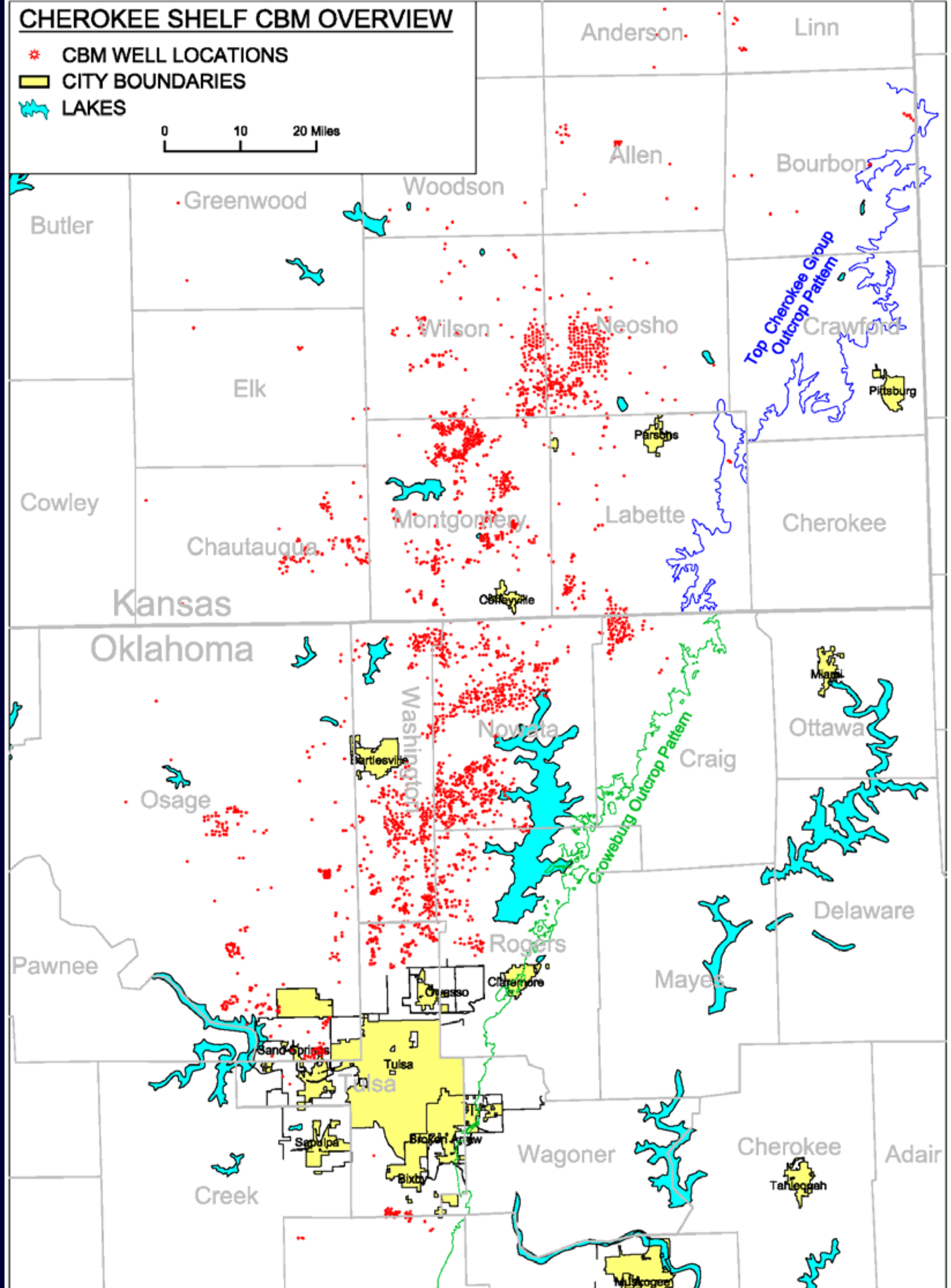
Okmulgee
Muskogee
Sequoyah
Okfuskee
Probable Extent of Hartshorne Coal Seam
Mcintosh
Haskell
Hughes
Pittsburg
Latimer
Le Flore
OKLAHOMA
ARKANSAS
Coal
Atoka
Pushmataha
Arkoma Basin CBM Overview
HARTSHORNE SEAM OUTCROP
NORMAL FAULTS
THRUST FAULTS
ANTICLINES
SYNCLINES
CBM WELL LOCATIONS
HARTSHORNE COAL TREND
0
15
30 Miles


CHEROKEE SHELF CBM OVERVIEW
CBM WELL LOCATIONS
CITY BOUNDARIES
LAKES
0
10
20 Miles
Anderson
Linn
Allen
Bourbon
Woodson
Greenwood
Butler
Wilson
Neosho
Crawford
Top Cherokee Group Outcrop Pattern
Pittsburg
Elk
Parsons
Cowley
Chautauqua
Montgomery
Labette
Cherokee
Coffeyville
Kansas
Oklahoma
Washington
Nowata
Craig
Miami
Ottawa
Bartlesville
Osage
Crowsburg Outcrop Pattern
Delaware
Pawnee
Rogers
Mayes
Owasso
Claremore
Sand Springs
Tulsa
Tulsa
Sapulpa
Broken Arrow
Bixby
Wagoner
Cherokee
Adair
Tahlequah
Creek
Muskogee

Permeability Testing

- Pressure transient analysis provides permeability, skin factor, extrapolated reservoir pressure
- Recommend pre-stimulation injection-falloff testing
- Reliable low-cost data with surface build-up testing, providing composite permeability and most-stimulated seam skin

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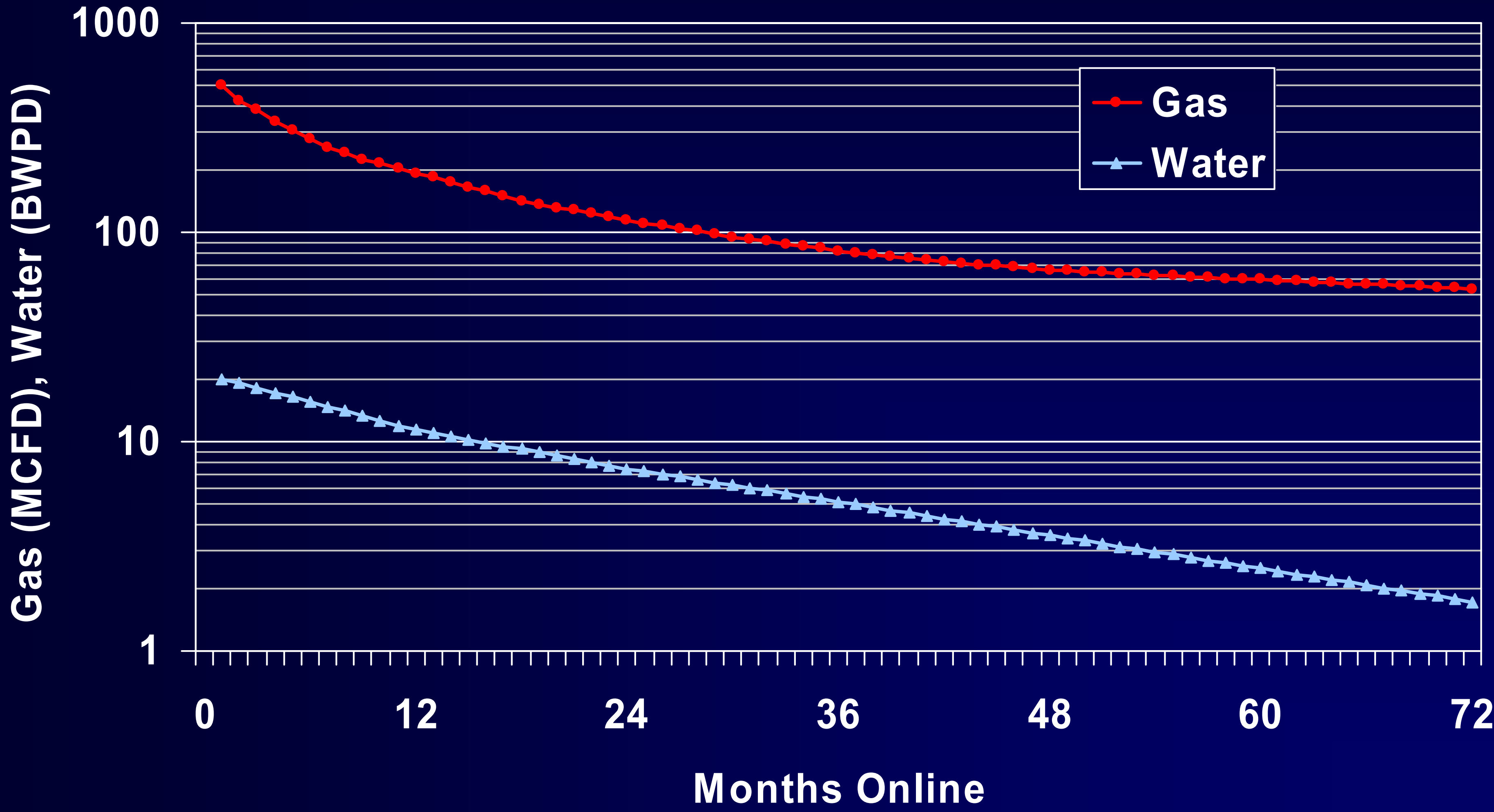
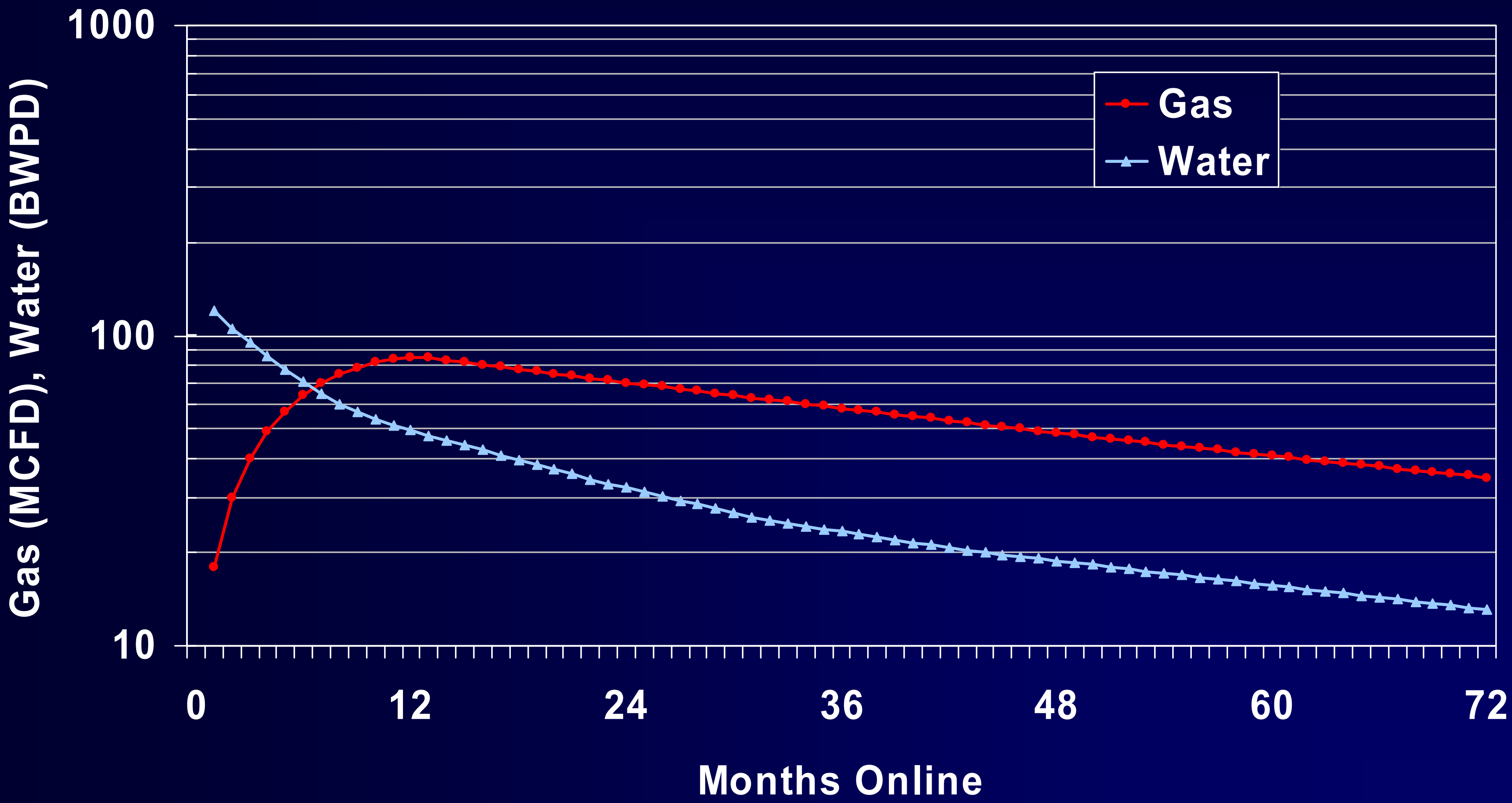
Well Types

- High structure wells behave like conventional gas wells with hyperbolic gas production decline
- Low structure wells have a classic CBM incline-decline profile and produce more water

Production Graph
High Structure Well



Production Graph
Low Structure Well



Completions

Completion Criteria

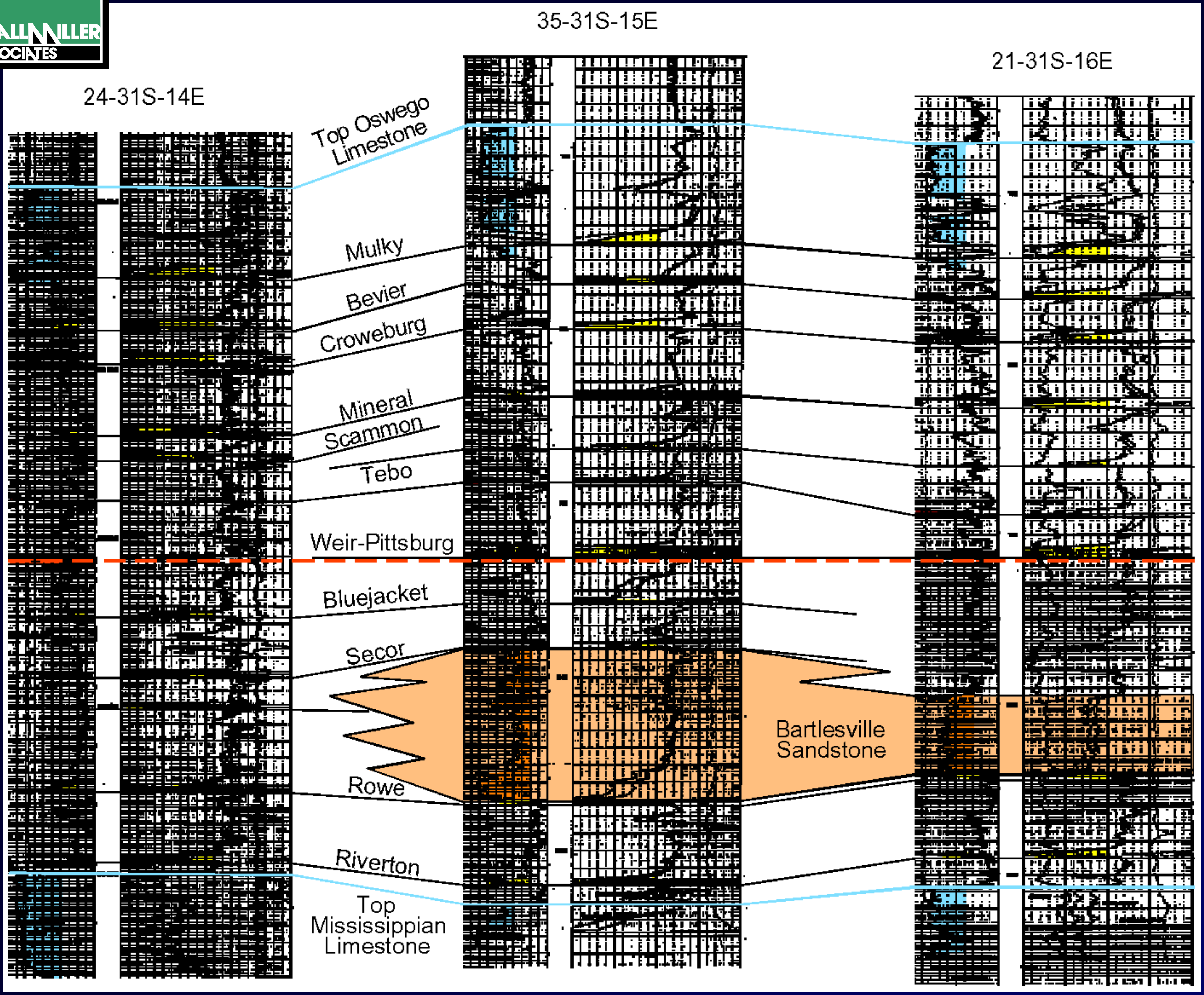
- Select clean (GRU < 75) coal seams with acceptable thickness
- Complete in separate frac stages whenever possible
- Run cement bond/correlation log on same scale as the open-hole density log
- Recommend four perforations per foot of coal, shooting top and bottom, with 90° or 120° phasing, except in multiple-seam stages
- May want to overshoot thin seams

Frac Treatments

- Optimal treatments place 1,000 to 5,000 pounds of proppant per foot of coal
- Low treatment rates generally better, limiting fines generation and fracture height growth in deeper coals
- Low gel loading is better
- More rate sometimes required to place sand with less gel or in multi-seam frac stages
- Know your treatment fluids

Treatment Fluids

- Know the reason for and effects of all fluids, chemicals, and additives
- Some surfactants and gels can be damaging with up to 85% matrix permeability loss
- Treatment fluids can be reliably evaluated in core plugs
- Case studies – damaging gels and surfactants


24-31S-14E
35-31S-15E
21-31S-16E
Top Oswego Limestone
Mulky
Bevier
Croweburg
Mineral
Scammon
Tebo
Weir-Pittsburg
Bluejacket
Secor
Bartlesville Sandstone
Rowe
Riverton
Top Mississippian Limestone

Fracing Out of Zone

- Communication with adjacent wet permeable formations can:
  - Require pumping large water volumes
  - Allow coal seam invasion and scaling
  - Introduce corrosive water
- Examples:
  - Bluejacket Coal / Bartlesville Sandstone
  - Rowe Coal / Tucker Sandstone
  - Riverton Coal / Mississippi Limestone

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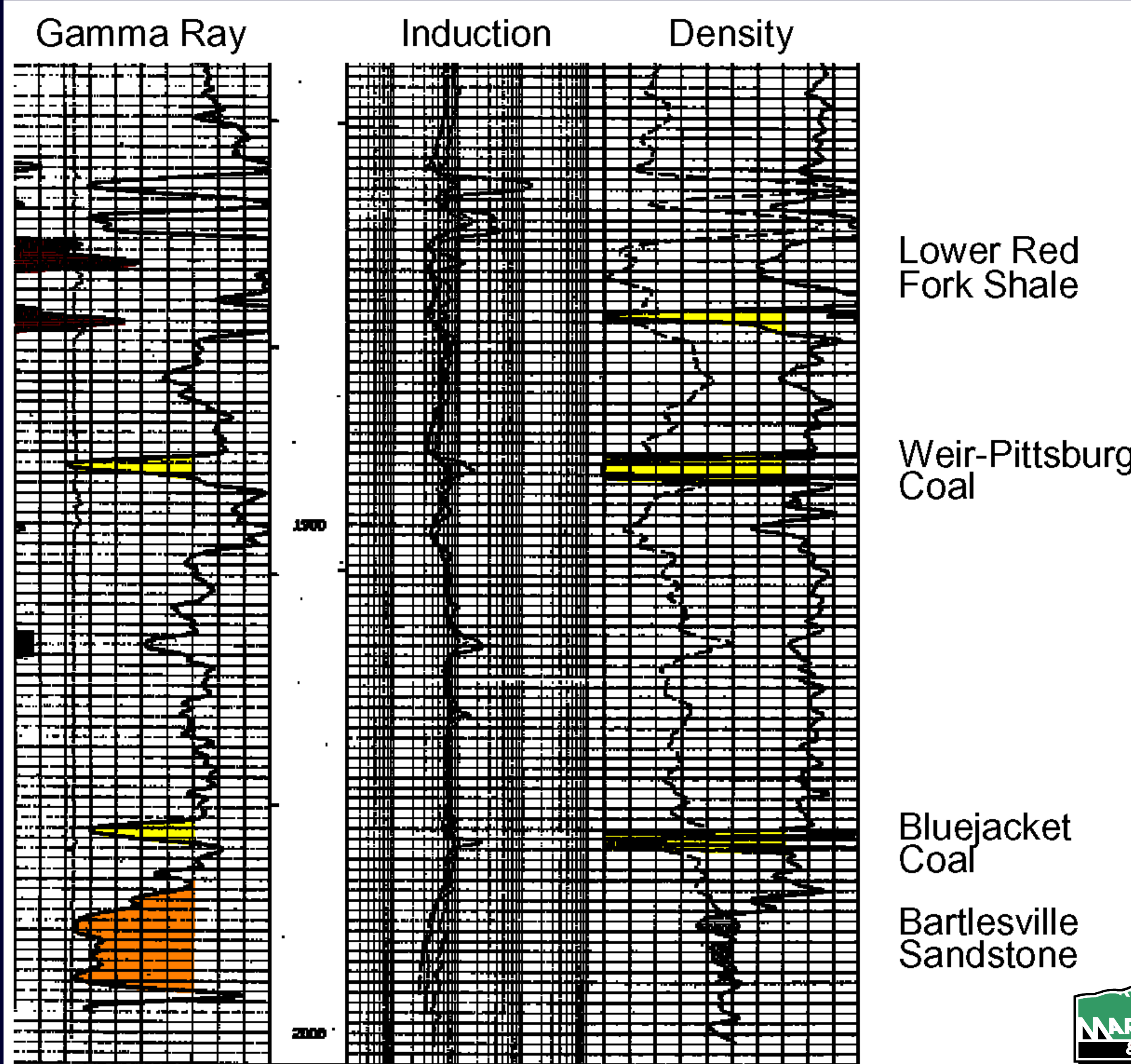
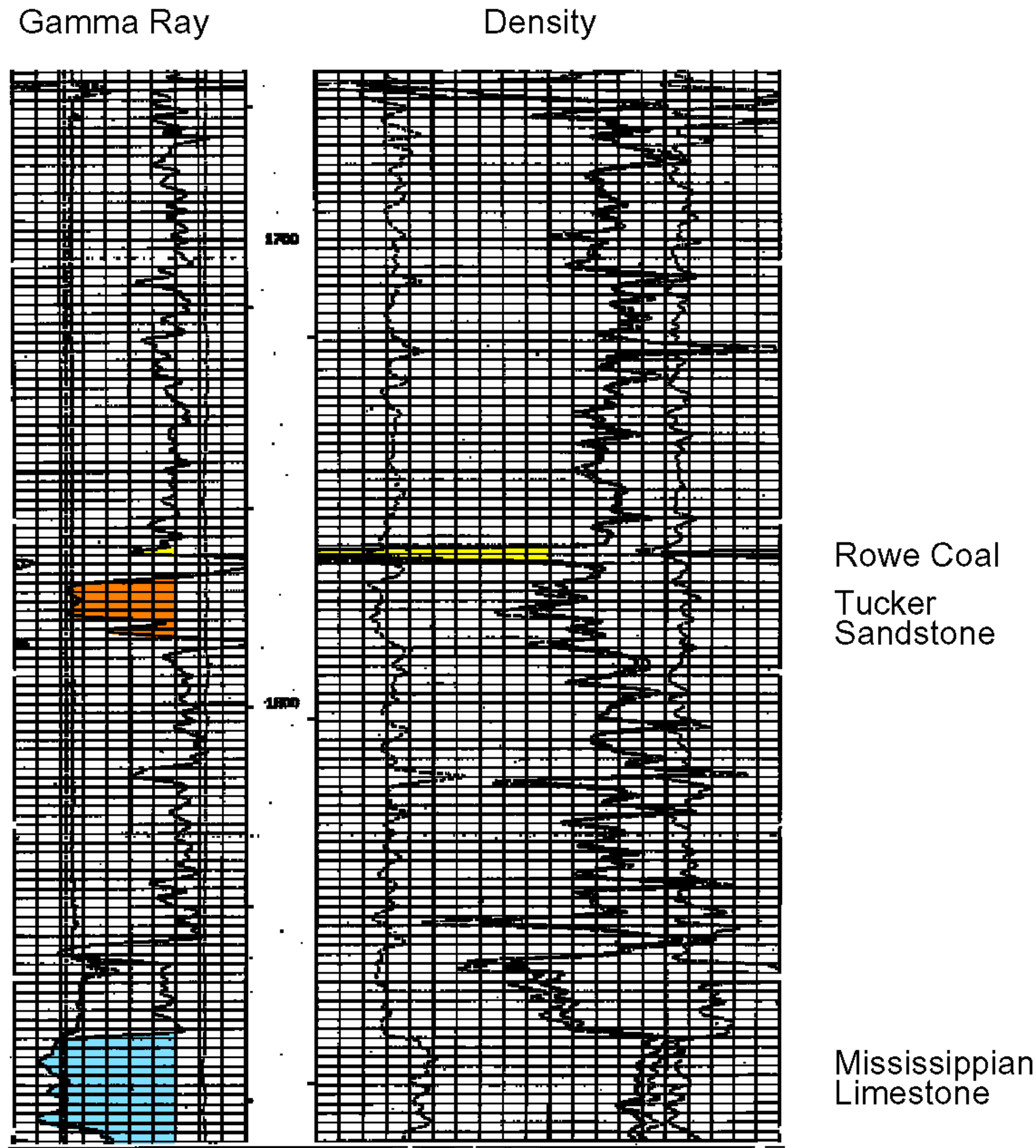
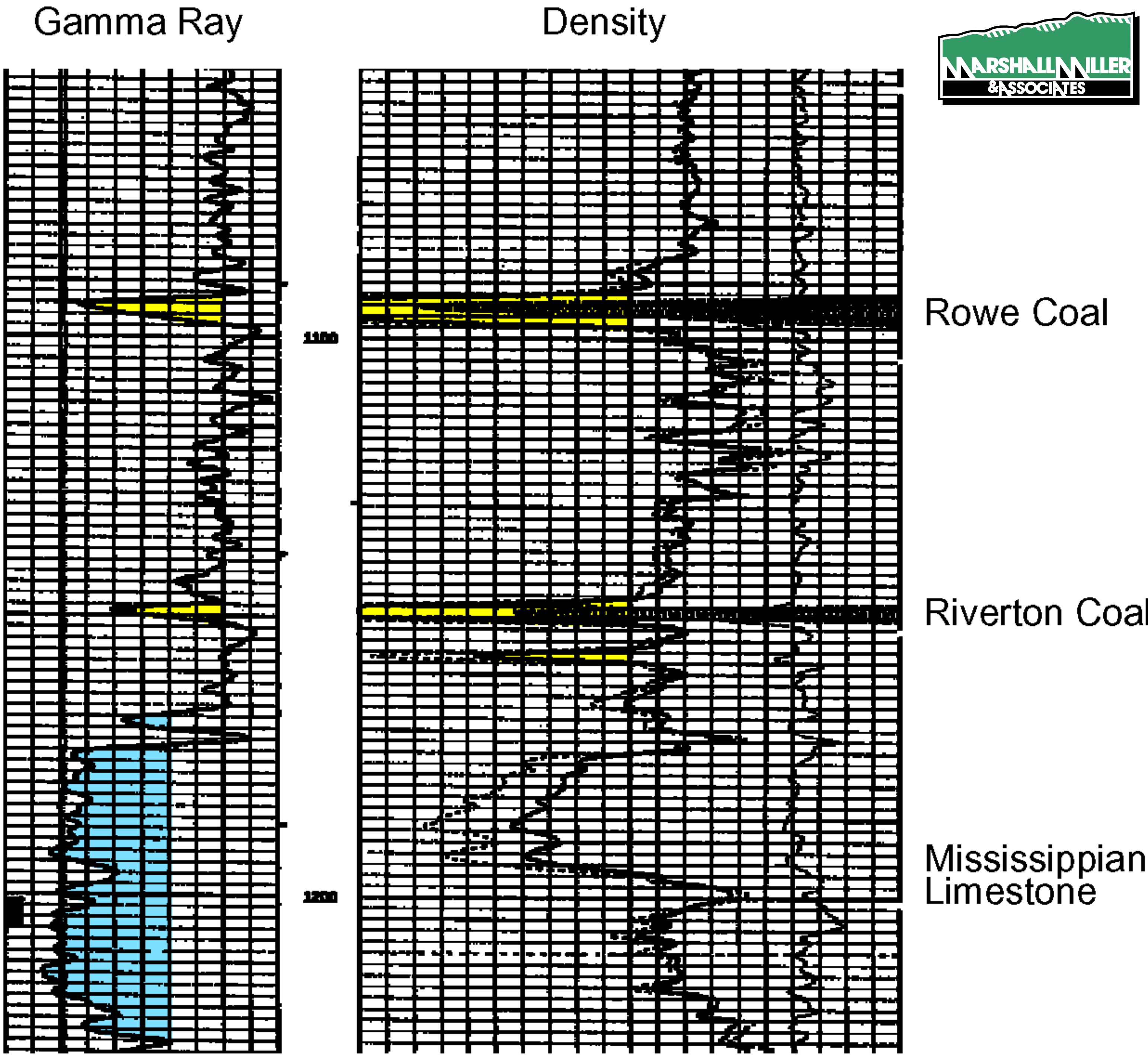

Gamma Ray
Induction
Density
1900
2000
Lower Red Fork Shale
Weir-Pittsburg Coal
Bluejacket Coal
Bartlesville Sandstone


Gamma Ray
Density
Rowe Coal
Tucker Sandstone
Mississippian Limestone



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Radioactive Tracer Surveys

- Evaluate whether horizontal or vertical fractures
- Evaluate frac height growth
- May alter completion-zone selection, frac staging, and treatment design depending on results

Production

On-line Procedure

- Shut the well in after frac
- Install tubing, rods and pump and start pumping ASAP after frac plugs removed
- Initially pump well with casing shut-in, monitoring the wellbore liquid level
- Gradually open casing after pressure stabilizes

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Procedure Benefits

- Mitigate sand production
- Minimize coal fines plugging
- Prevent gas pockets forming that can reduce near wellbore relative permeability to water thereby slowing dewatering
- Reduce cross-flow that can cause scale and emulsion problems and potentially deep invasion of lower coal seams

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Producing the Wells

- Stress-dependent permeability can sometimes cause cleat closure, reducing effective permeability and producing rate
- Slowly lower casing pressure
- If producing rate drops or wellbore liquid level rises, do not reduce the casing pressure further and perhaps increase it
- Casing pressure eventually should be very low to desorb and produce maximum gas, but be careful early in the well life

Production Testing

- Consider individual seam production testing
- Costly, but probably will save money in the long run
- Can help determine which seams are economic to complete
- Obtain and have analyzed individual seam water whenever possible
- Obtain good water production data

Production Monitoring

- Closely monitor gas and water production and casing and tubing pressures, especially on new wells
- Record the data
- Graphically evaluate the data
- A good data management system helps

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Graphic Data Evaluations

- Composite project-level production
- Composite geological or geographical area production
- Time-zero average well production for project and areas, indicating well count
- Composite production for wells completed in various coal seams
- Time-zero average well production for well groups completed in various coal seams
- Time-zero gas/water ratio for project and areas
- Peak well production versus completed gas-in-place

Coal Seam Restimulation

- Refracing individual coal seams originally fraced together in a common treatment stage have provided good production responses
- Refracing seams apparently damaged by completion fluids have shown good responses when treatments are sufficiently large

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Summary

- Gather good data, especially early time
- Analyze the data and learn from it
- Talk to other operators to quickly move up the learning curve
- Learn the idiosyncrasies of your own development since they are all different

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