Identification of Fracture Stimulation Stage and Well Interference

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Roke Technologies

Agenda

- Review Objectives
- HZ Fracturing Development Risks
- Marcellus Formation
- Methodology
- Data Acquisition
- Operational Summary
- Conclusions

Primary Objective: Find Optimum Well Spacing

Secondary Objective: Find Optimum Frac Stage

Development Risks

- Sanding off guns
- Stuck in hole
- Large variance breakdown pressures
- Operational efficiency improvement
- Optimize single biggest cost

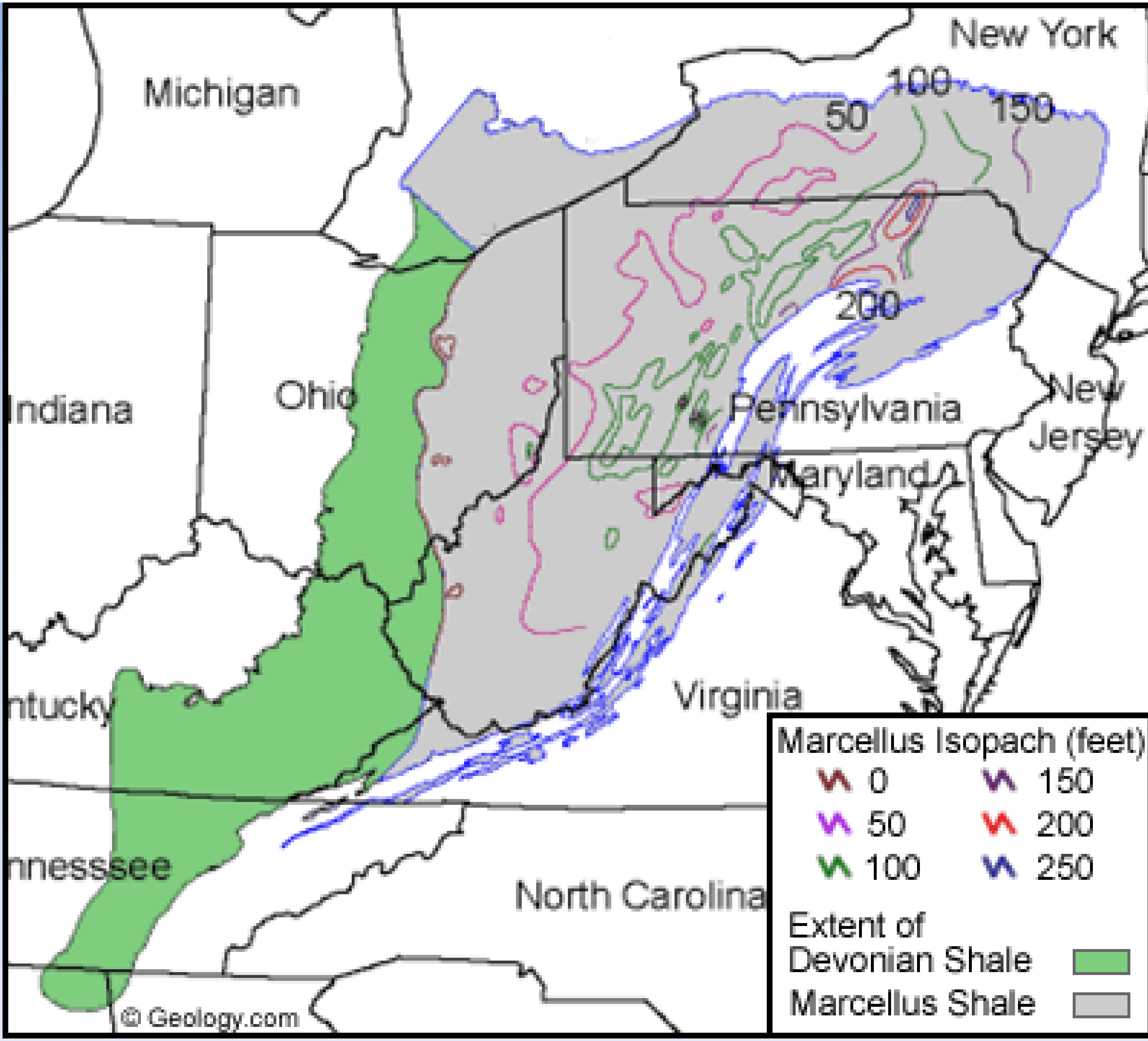
Marcellus Development Timeline

- 19th Century the outcrops were mined for coal
- Vertical wells 50+ years
- 2003 Marcellus Discovery

  PA – Range Resources.
- 2010 Range Resources Q3 Production

  190 MMCFDE

  164 HZ wells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© Geology.com
Marcellus Isopach (feet)
0
150
50
200
100
250
Extent of Devonian Shale
Marcellus Shale

Why the Marcellus?

- Proximity to markets
- Large areal extent
  - Up to 95,000 square miles (60 million acres)
  - 50 to 200 feet thick
- Horizontal drilling and fracturing
- Increasing reserve estimates

Marcellus Reserve Estimates

- 2002 USGS

  Estimated 1.9 TCF recoverable

- 2006 Engelder and Lash

  Estimated 49 TCF recoverable

  From 490 TCF GIP using10% RF

- 2008 Engelder and Lash

  Estimated 1307 TCF recoverable

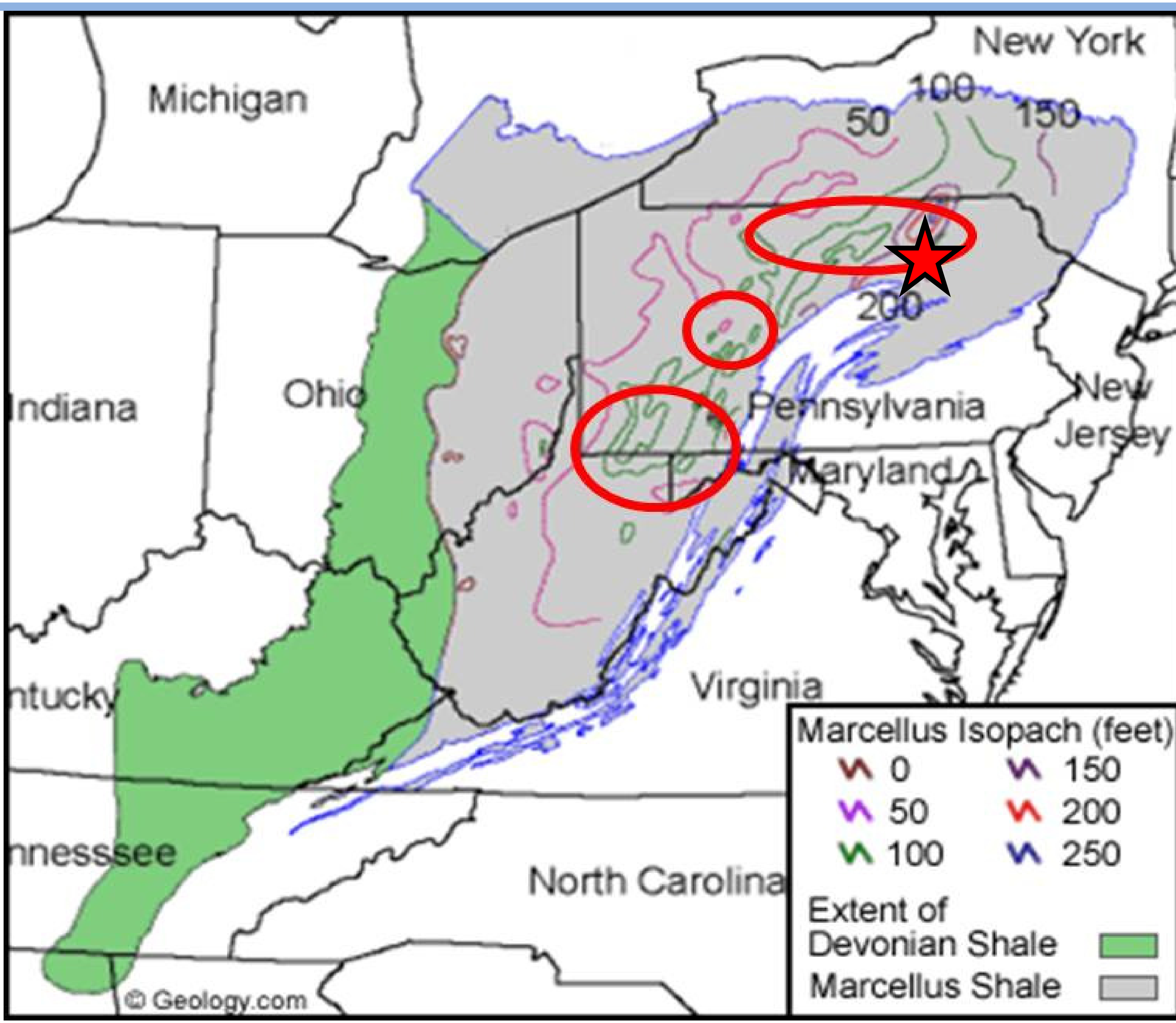
  From 4359 TCF GIP* using 30 % RF

  *Assumes the entire Marcellus is productive

- 2009 US DOE

  Estimated, and 262 TCF recoverable

  From 1500 TCF GIP using 17.5 % RF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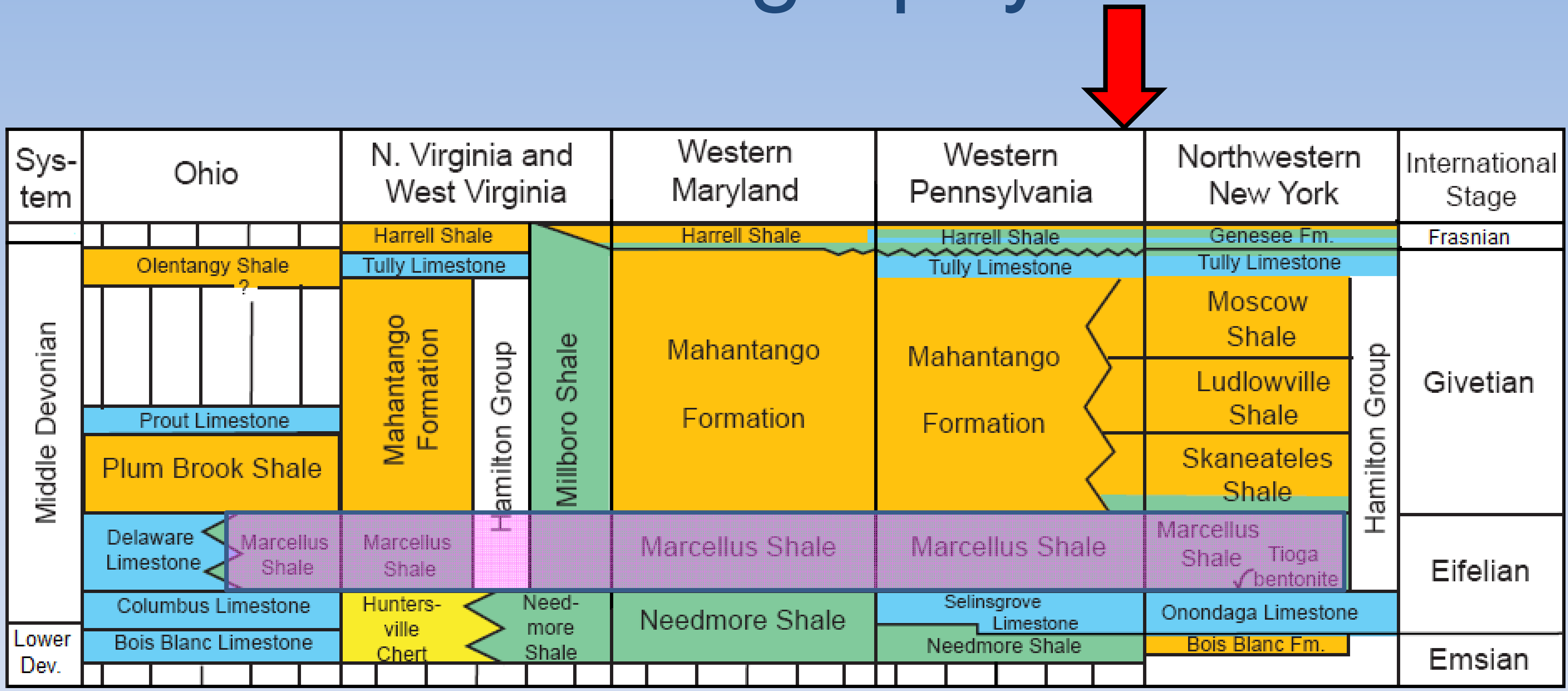
Stratigraphy



Project Timeline Summary

- Drill and case 2 HZ wells

  750 ft spacing

- 1st Quad Neutron run on each well
- Fracture stimulation 1 well
- 2nd Quad Neutron run on each well

Non-radioactive Frac Tagging

CB4

- Neutron Neutron
- Neutron Gamma

Sand

- Neutron Neutron
- Neutron Gamma

First Log Evaluation

- Primary Objective:

  Neutron Neutron and Neutron Gamma Baseline

- Secondary Objective:

  Lithology, porosity and saturation

  Identify geological facies along HZ

  Identify areas of high reservoir quality

Fracture Stimulation

- Pump down plug and perf
- 400 ton slickwater fracs
- 280 ft spacing

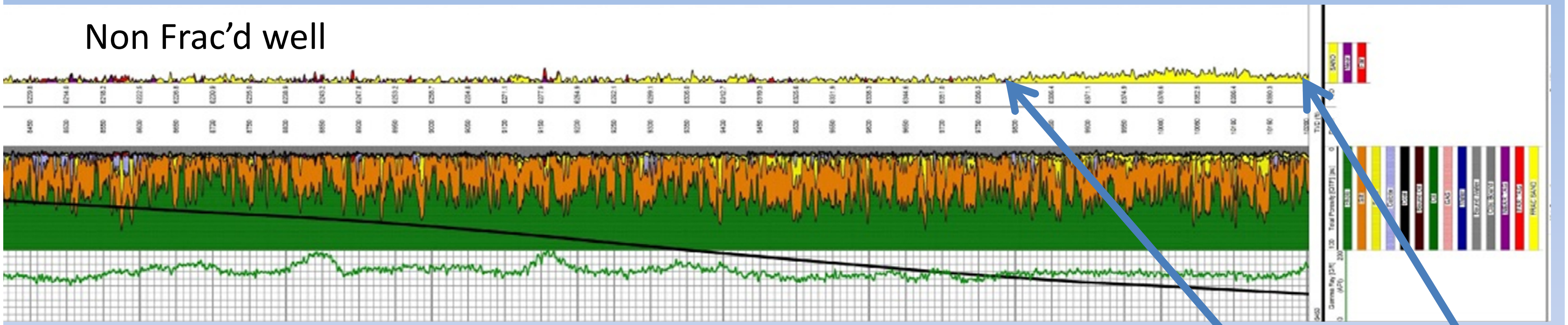
  Alternating CB4 and Sand tag

- ~7 limited entry perfs per stage

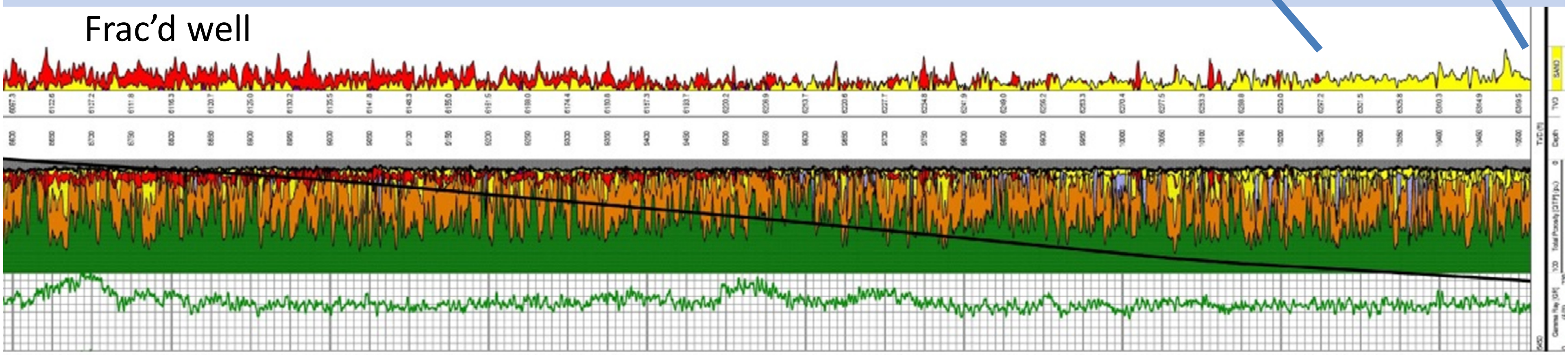
  280 ft / 7 = 40 ft

Well Interference

Non Frac'd well



Frac'd well



Well Interference Summary

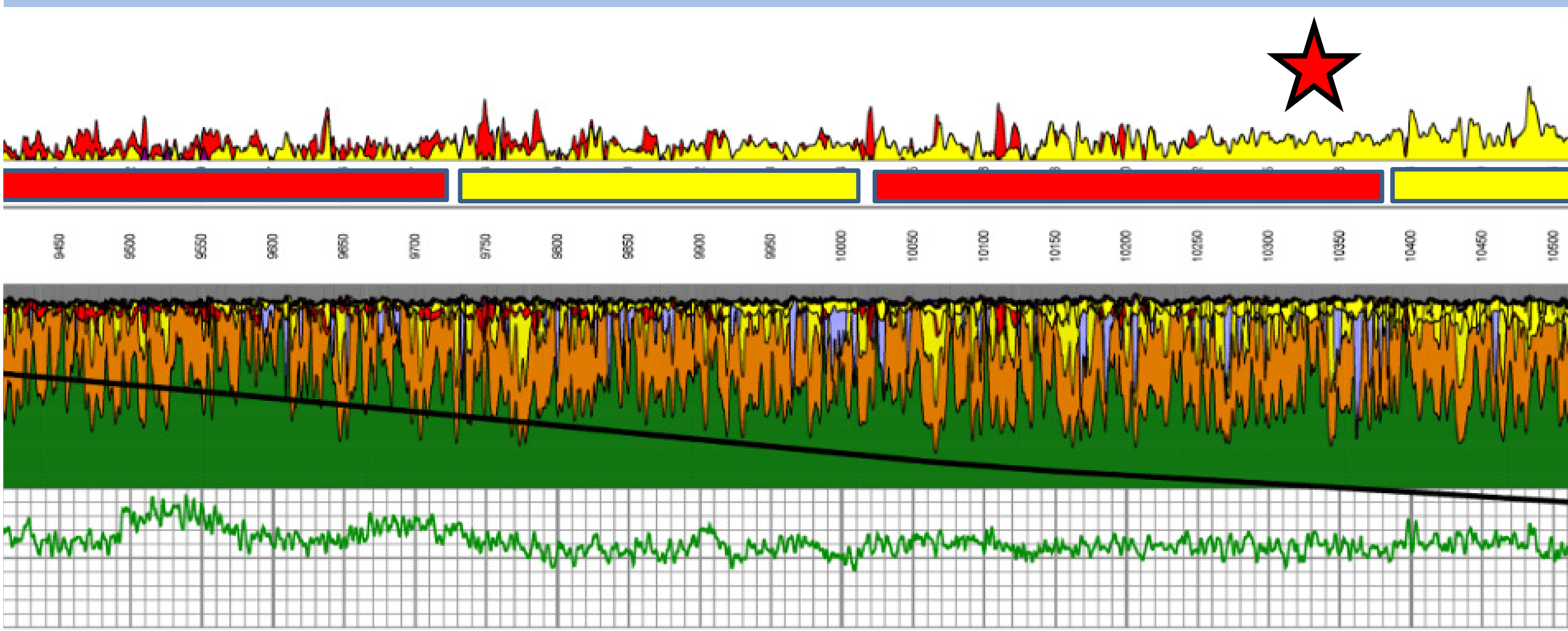
- Well interference confirmed

  Large Sand tag – toe

  CB4 and Sand – throughout well

- Frac propagation along structure

Stage Interference



Stage Interference Summary

- Stage interference confirmed
- Over 100 ft at stage one
- Multiple stage inference confirmed

Data Acquisition / Analysis Costs

- $85k for two wells – 4 logging runs
  - Quad Neutron
  - Frac Tag
  - Analysis
  - Conveyance
    - 2 plug pump down & 2 coil
    - Conveyance reduced with drilling pump down

Conclusions

- Optimize fracture stimulations

  Maximize resource recovery

  Minimize biggest cost

- Identify faults / structure influence frac

Acknowledgements

- Hermann Kramer

  Roke Technologies
- Tiffiny Yaxley

  Roke Technologies
- Joe Sites

  Horizontal Wireline

Questions?

- Jay Williams

VP Americas, Onshore

Roke Technologies

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Quad Neutron: Open Hole Alternative

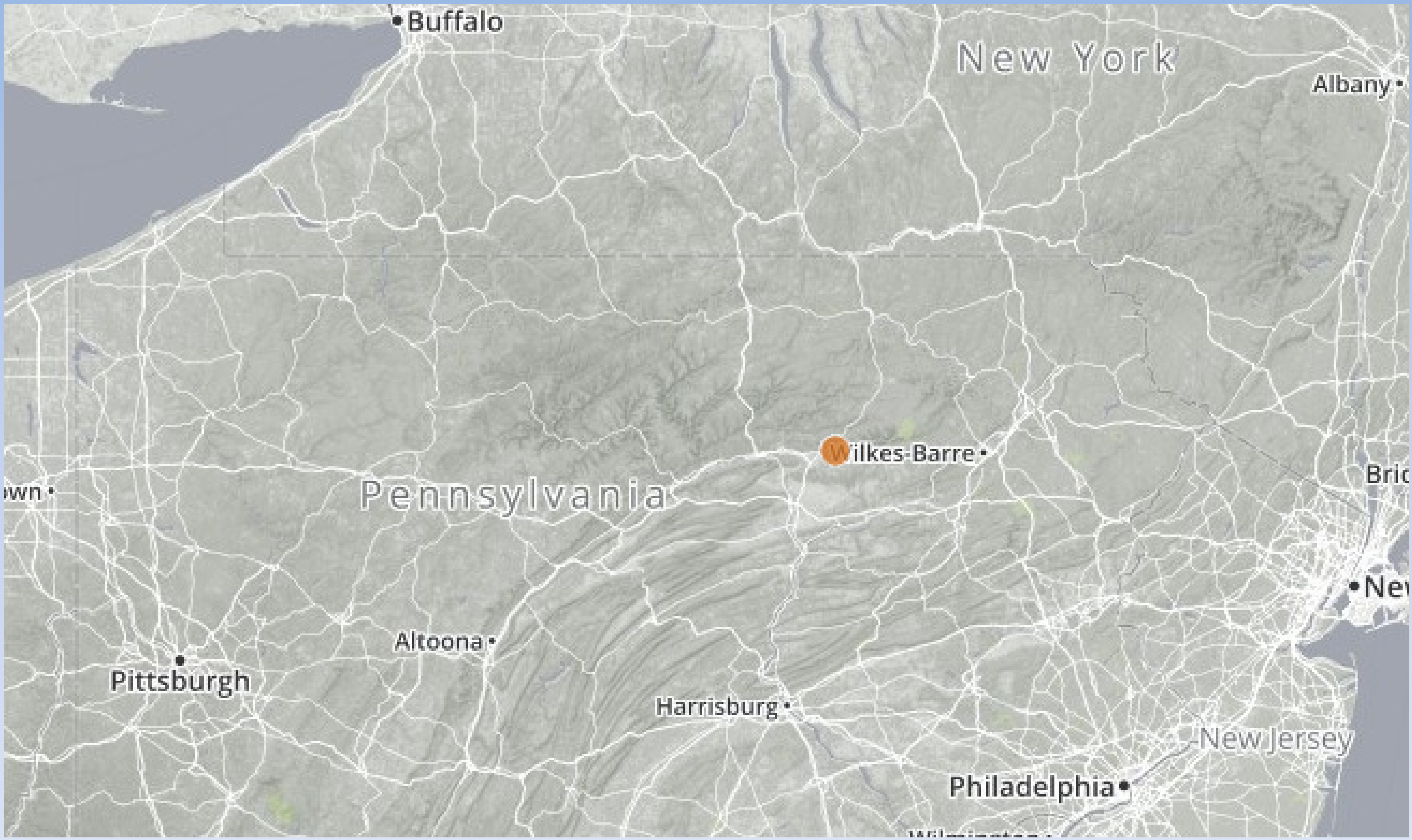
Additional Slides

Successful Hz Frac Stimulations

- Increase production and lower cost

Optimize Well Spacing / Frac Stage Spacing

Erie
Jamestown
Ithaca
Elmira
Binghamton
Allegheny
National Forest
Warren
Youngstown
New Castle
Canton
Scranton
Wilkes-Barre
Hazleton
PENNSYLVANIA
Pottsville
Bethlehem
Allentown
Altoona
Pittsburgh
Johnstown
Harrisburg
Reading
Lancaster
Philadelphia
Wheeling
York
Wilmington
Morgantown
Hagerstown
MARYLAND


Buffalo
New York
Albany
Wilkes-Barre
Pennsylvania
Altoona
Pittsburgh
Harrisburg
New Jersey
Philadelphia

Open Hole vs Quad Neutron

Conventional Open Hole

- Lithology

  Natural Gamma Ray / PE

- Porosity

  Neutron

  Density

  Introduced gamma

- Saturation

  Resistivity

  Archie’s Equation

Quad Neutron (Thru Pipe)

- Lithology

  Quad Clay / CE (Bulk Den)

- Porosity

  Neutron Neutron

  Neutron Gamma

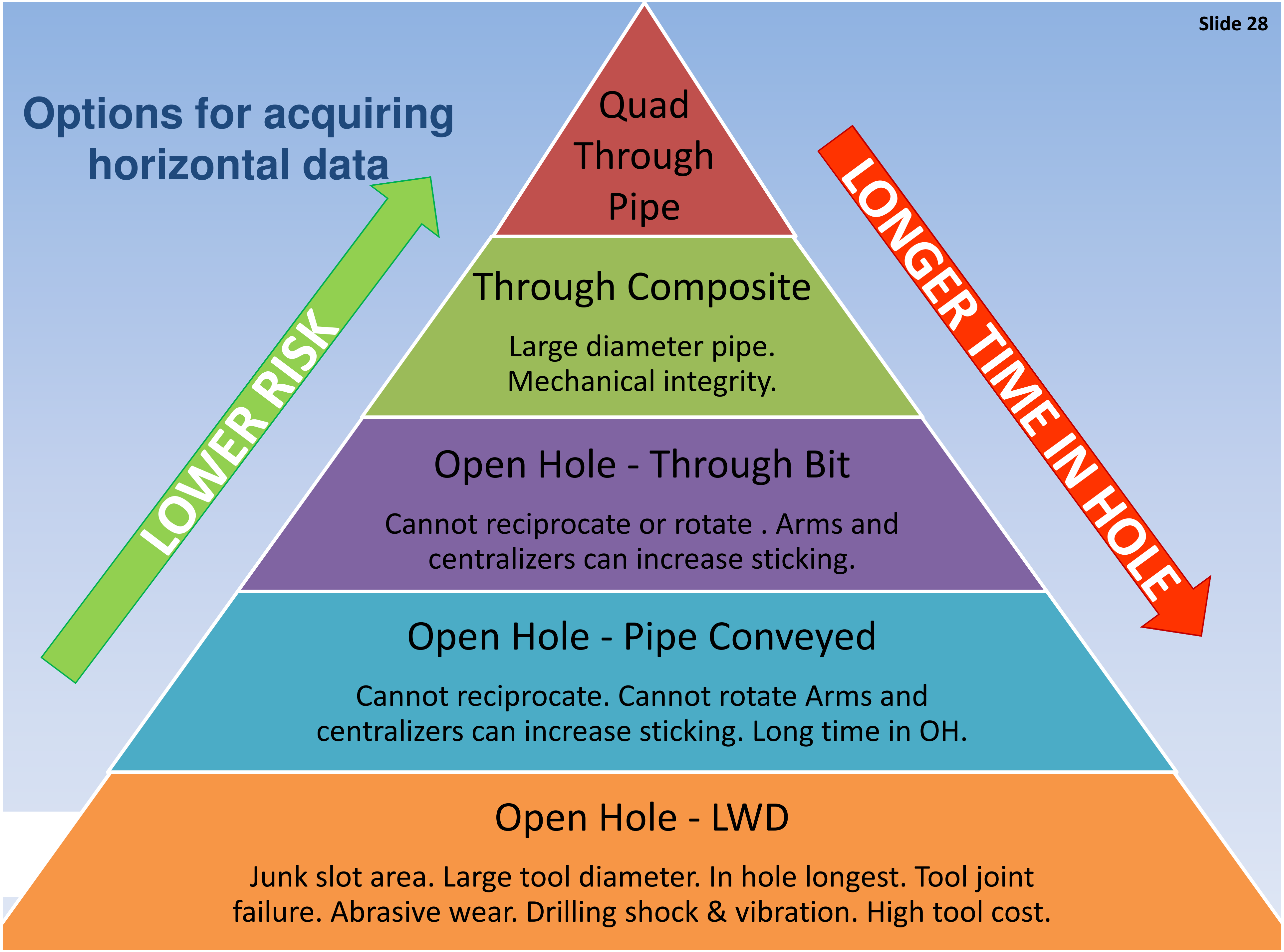
  Induced gamma

- Saturation

  Quad Liquid

  Roke’s Equation

Options for acquiring horizontal data



Find Oil

- Quad Neutron Open Hole Thru Pipe

  Exploration

  Completion

  Production

  Late Stage Due Diligence

“Swiss Army Knife”

Quad Neutron Dual Physics

- Minimizes Porosity Error
- Maximizes Fluid Sensitivity

$$2 + {}^{-}2 = 0$$

$$|2| + |{}^{-}2| = 4$$

Quad Neutron Physics

- Two types of neutron interaction:
  - neutron-gamma (high energy)
  - neutron-thermal neutron
- Combination of the two physics:
  - Maximizes porosity accuracy
  - Maximizes fluid sensitivity
- Same source
  - reduces statistical error

Quad Neutron – Data Acquistion

- Horizontal Wells

  Pump Down Drilling Rig Deployment

    During Wiper Trip

  Coil Tubing / E-Coil Deployment

  Tractor Deployment

  CoRod Deployment

  Jointed Pipe Deployment

Thermal Neutron Nuclides

Parent Nuclide	Abundance (percent)	Daughter Nuclide	Counts per second per gram after 2 min irradiation[1]
^{27}Al	100	^{28}Al	27000
^{37}Cl	24.5	^{38}Cl	810
^{41}K	6.88	^{42}K	190
^{26}Mg	11.2	^{27}Mg	310
^{55}Mn	100	^{56}Mn	12000
^{23}Na	100	^{24}Na	210
^{30}Si	3.09	^{31}Si	6

[1] Based on 10 percent counting efficiency, a flux of 10^8 n/cm^2 sec, and a normal abundance of nuclides. (After Senftle and Hoyt (1966), with additional data from Goldman and Stehn (1961))