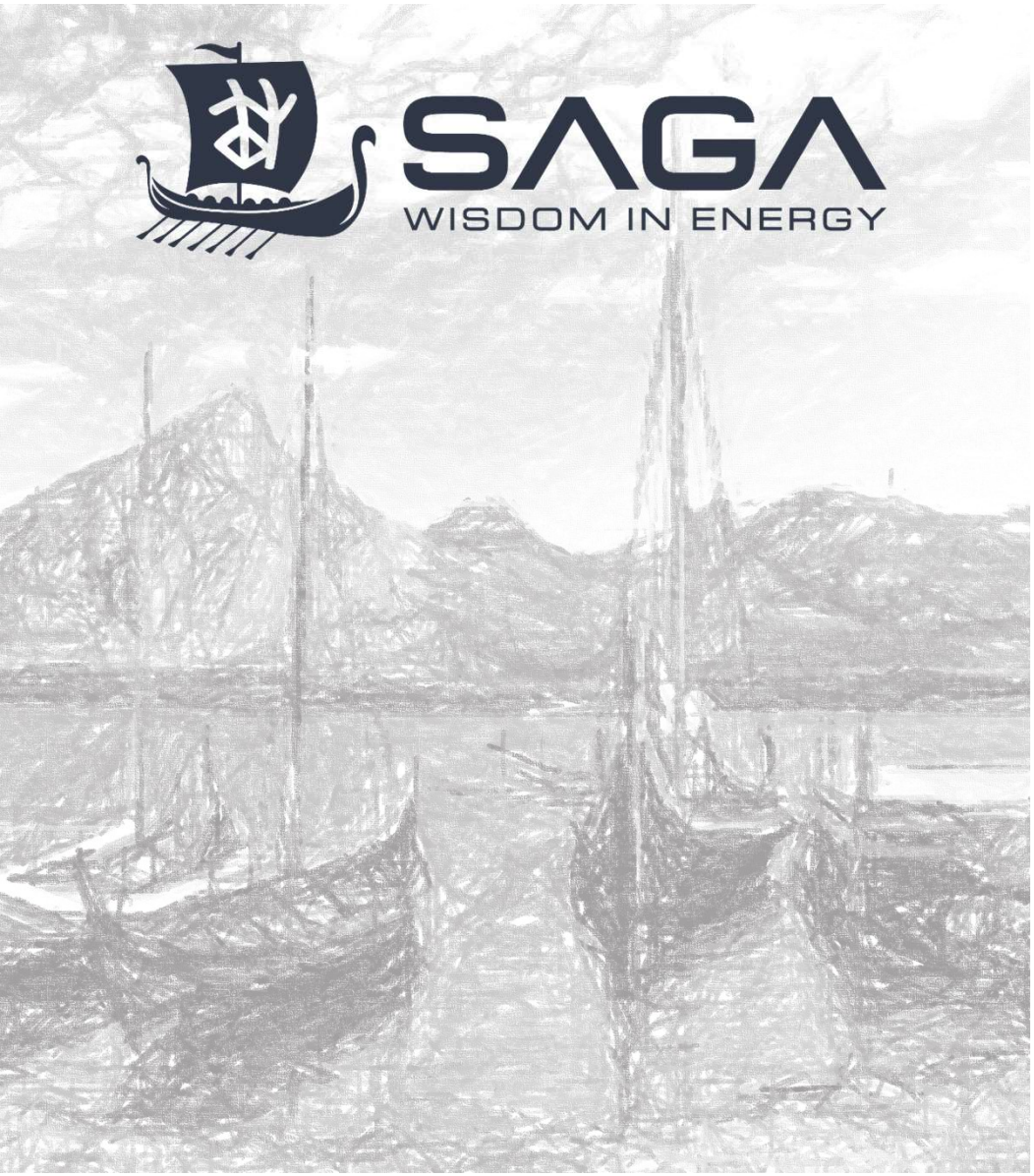
A Reservoir Engineer's Guide to Fit-for-Purpose Completions- Minimum Spend for Maximum Performance

David Anderson, CEO

SAGA
WISDOM IN ENERGY



On-demand training for the energy industry

- Masterclass instructors and content in the following areas- *Reservoir, Operations, Completions, Geoscience, Analytics* and *Machine Learning*

- Guided, collaborative training programs targeted toward specific business objectives, vetted by E&P steering committee

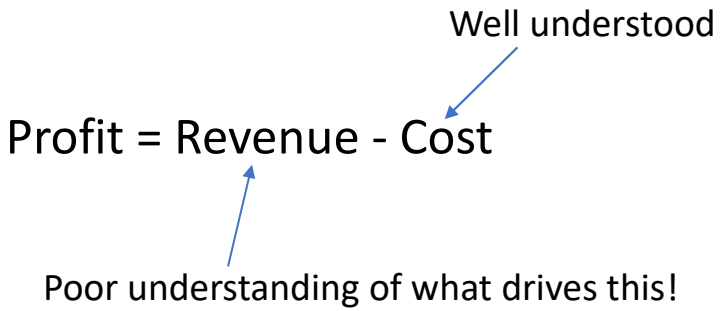
- Annual subscription service with access to unlimited online content and live engagement with experts/consultants

sagawisdom.com **info@sagawisdom.com**

Fit-For-Purpose Completion

=

Most profitable allocation of completion capital



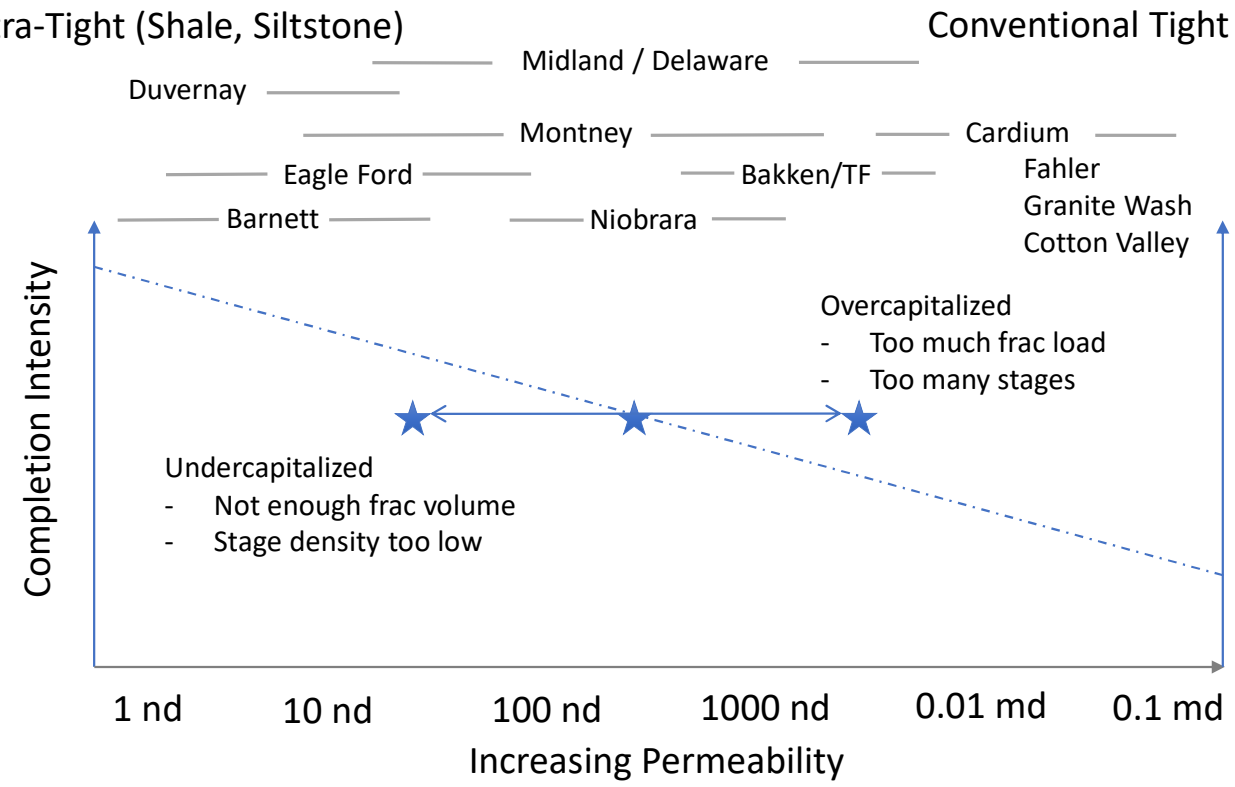
Fit-For-Purpose Completions - Decisons

- Landing depth
- OH or cemented liner?
- Perf, ball drop or sliding sleeve?
- Number of frac stages
- Number of clusters
- Type and amount of diverter
- Proppant load per meter
- Proppant load per stage
- Proppant concentration
- Proppant type and schedule
- Frac fluid type and schedule
- Pump rate

The combined cost of these decisions routinely exceeds 50% of the total capital cost of well construction

>$1.5 billion in the Montney alone in 2016

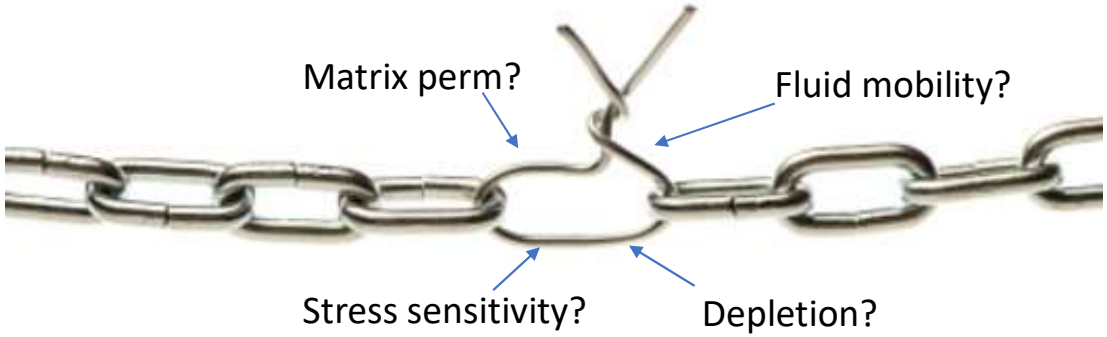
Common Operator Mistakes – Inflexible Design



Common Operator Mistakes – Misallocation of Completion Capital

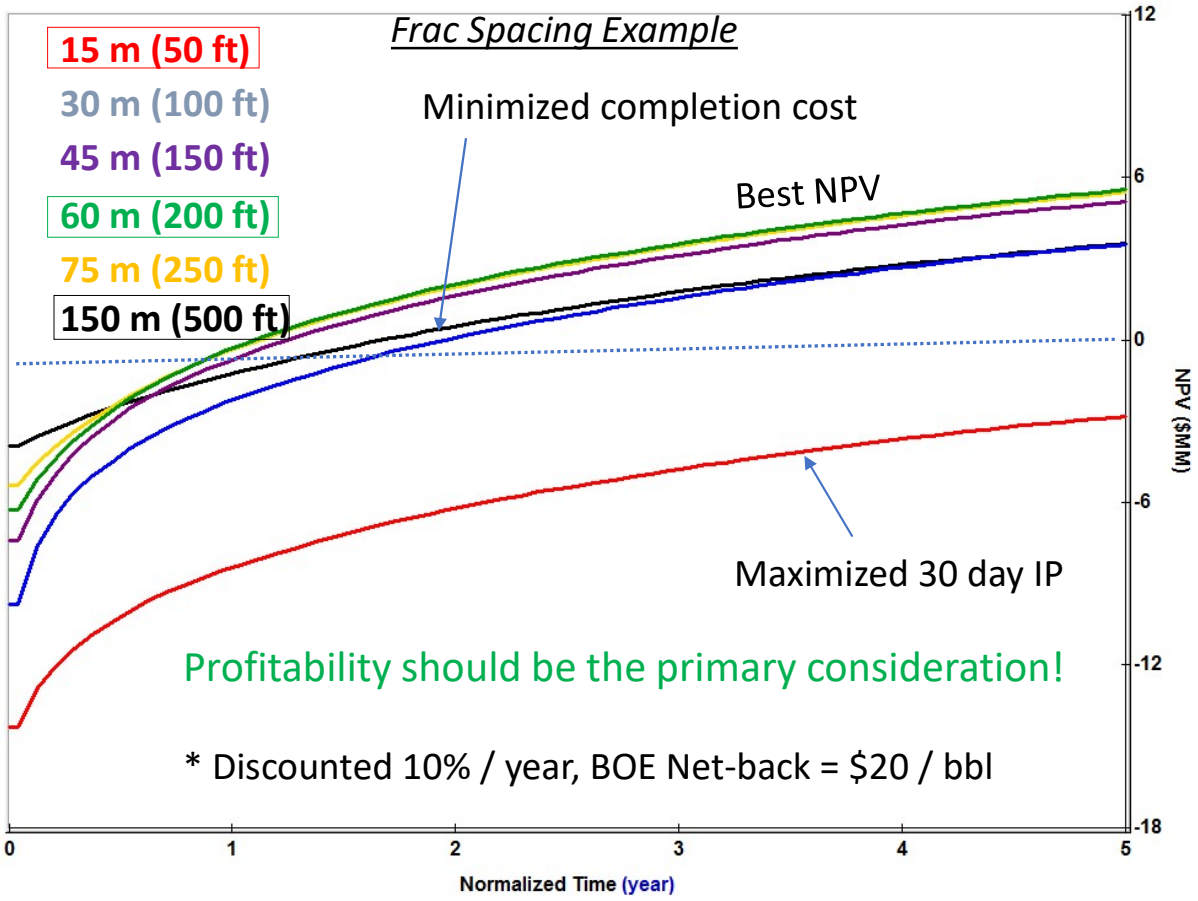
Operators routinely spend money bolstering “links” that are not weak. Eg-

- Designing high conductivity fracs in ultra low permeability plays
- Using high frac stage density in micro or millidarcy permeability



The trick is to figure out what the weak link is, and design your completion around strengthening it!

Common Operator Mistakes – Optimizing the Wrong Metric. Eg: Completion cost or 30 day IP



How can we ensure completions are “Fit-for-Purpose” and capital is allocated profitably?

- Understand the reservoir
  - What are the primary drivers of well performance?
  - Relate input variables to output performance (modeling)
- Layer in economics and run sensitivities
  - Optimize on profitability indicators

Why should you care?

- Effective allocation of completion capital is just one factor of many in deciding whether to invest in a company (or sell)
    - There are numerous companies who have no concept of “fit for purpose” but have stellar market performance
    - There are other companies that live by “fit for purpose” but have mediocre market performance
- However…..
    - Completion & stimulation is a multi-billion dollar spend, sooner or later its impact will be felt
    - The market (and most evaluators) in general have no understanding of how completion decisions relate to well performance (and therefore profitability)

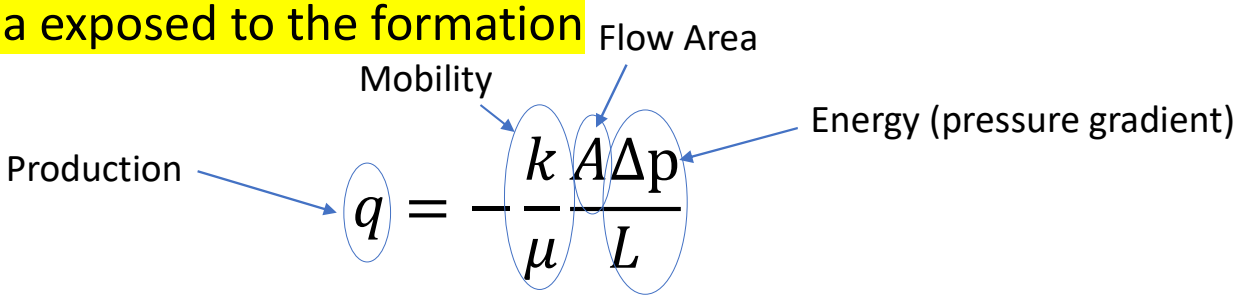
Top 5 Important Completion Decisions

- Frac surface area- treatment size
- Frac conductivity- fluid/proppant type, size and volume
- Frac complexity- fluid type, rock type, geomechanics
- Completion compartmentalization- stage spacing
- Well placement- landing depth and trajectory

- *Each reservoir requires a different formula!*

Fracture Area

- Primary production drivers
  - Source of energy – usually reservoir pressure
  - Mobility of the fluid
  - Flow area exposed to the formation

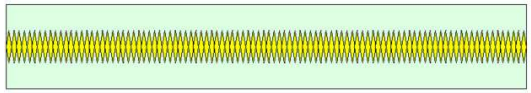


The impact of fracture area is much more significant in low mobility reservoirs

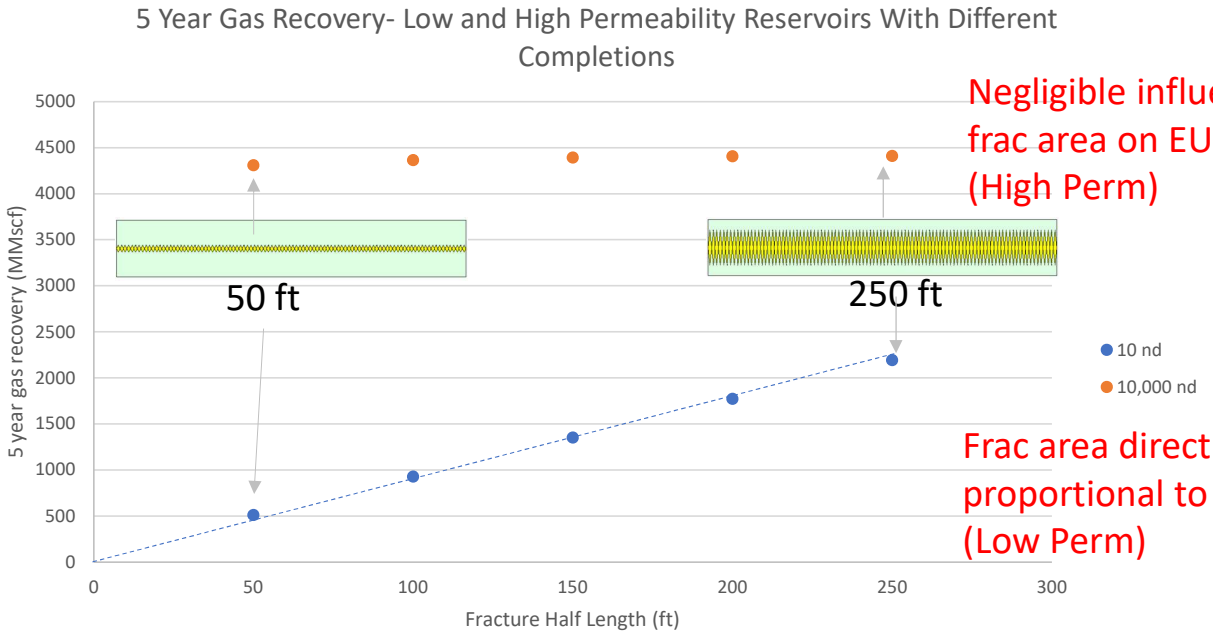
Importance of Frac Area

HP Hz Gas Well
800 ft drainage area
100 stage completion

Low perm 10 nd
High perm 10,000 nd



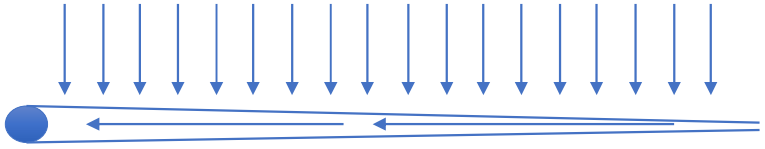
Adjust xf from 50 ft to 250 ft
What is the impact on 5 year EUR?



Negligible influence of frac area on EUR (High Perm)

Frac area directly proportional to EUR (Low Perm)

Frac Conductivity – Effectiveness Depends on Reservoir

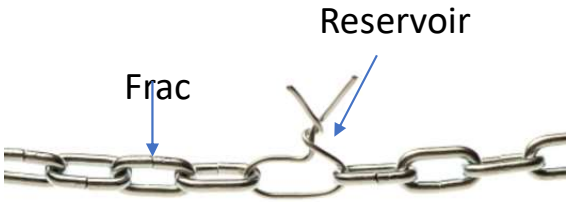


A hydraulic fracture must have a higher conductivity than the reservoir to be effective – C_{FD} = dimensionless conductivity

Eagle Ford – k = 0.0001 md

$C_{FD} = k_f w / kx_f = 1000$

Overcapitalized



Frac design-

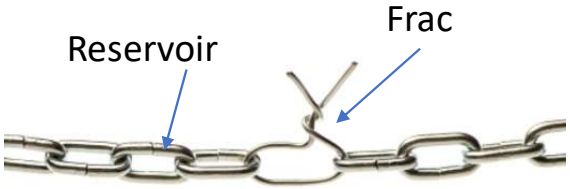
$k_f w = 15$ md.ft

$x_f = 150$ ft

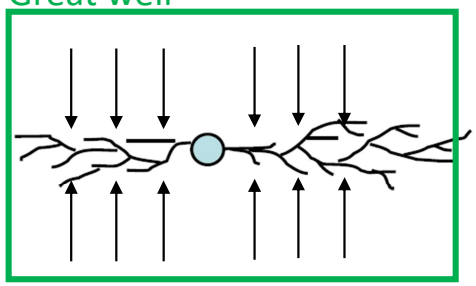
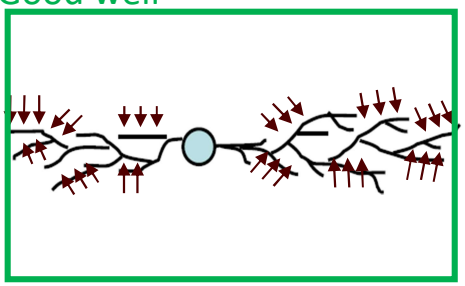
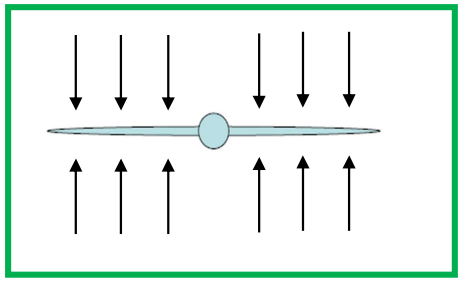
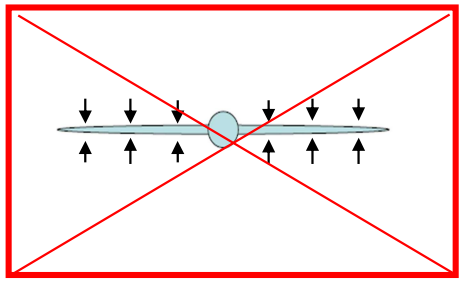
Cardium – k = 0.1 md

$C_{FD} = k_f w / kx_f = 1.0$

Undercapitalized



Frac Complexity – Why it is critical for ultra-tight oil

	Ultra-tight Gas	**Ultra-tight Oil**
Frac complexity	Great well  Diffusion through the matrix is viable transport mechanism for gas in ultra-tight rock	Good well  Oil will only flow through fractures in ultra-tight rock
No Frac complexity	Good well 	Poor well 

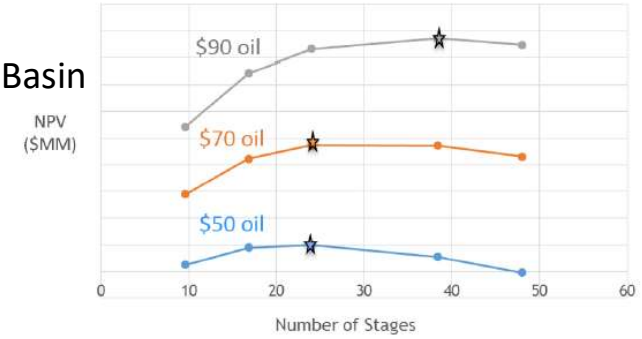
Frac Complexity –
“Keep telling yourself you can influence that”

- Frac complexity creates a multiplicity of total frac area; beneficial to well performance in *any* reservoir
- Frac complexity is a *dominant* performance driver in ultra-tight oil saturated reservoirs – Eg- Eagle Ford and Duvernay
- Frac complexity is *less important* in gas saturated reservoirs
- Influence of treatment design on frac complexity is minimal- controlled primarily by Mother Nature

- ***Increased stage density is an excellent substitute for fracture complexity***

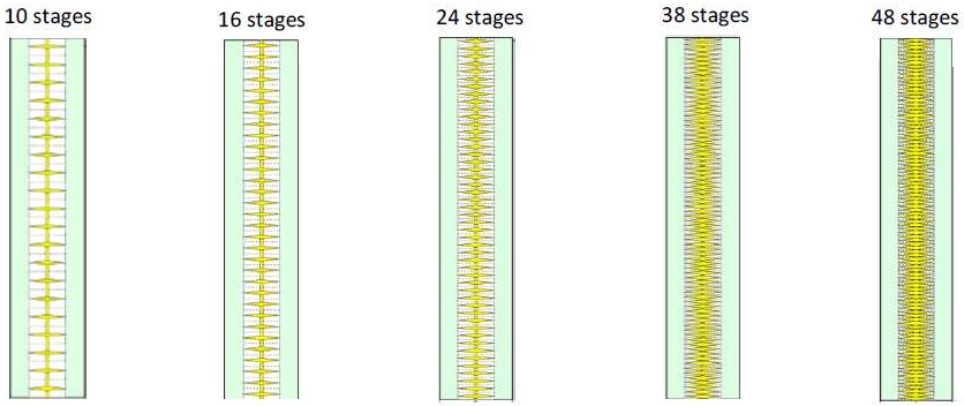
Completion Compartmentalization- Stage Spacing

Powder River Basin Example



Fit-for-purpose (optimized) stage spacing depends on:

- Oil price
- Completion cost
- Well spacing
- Frac design
- Expected well performance



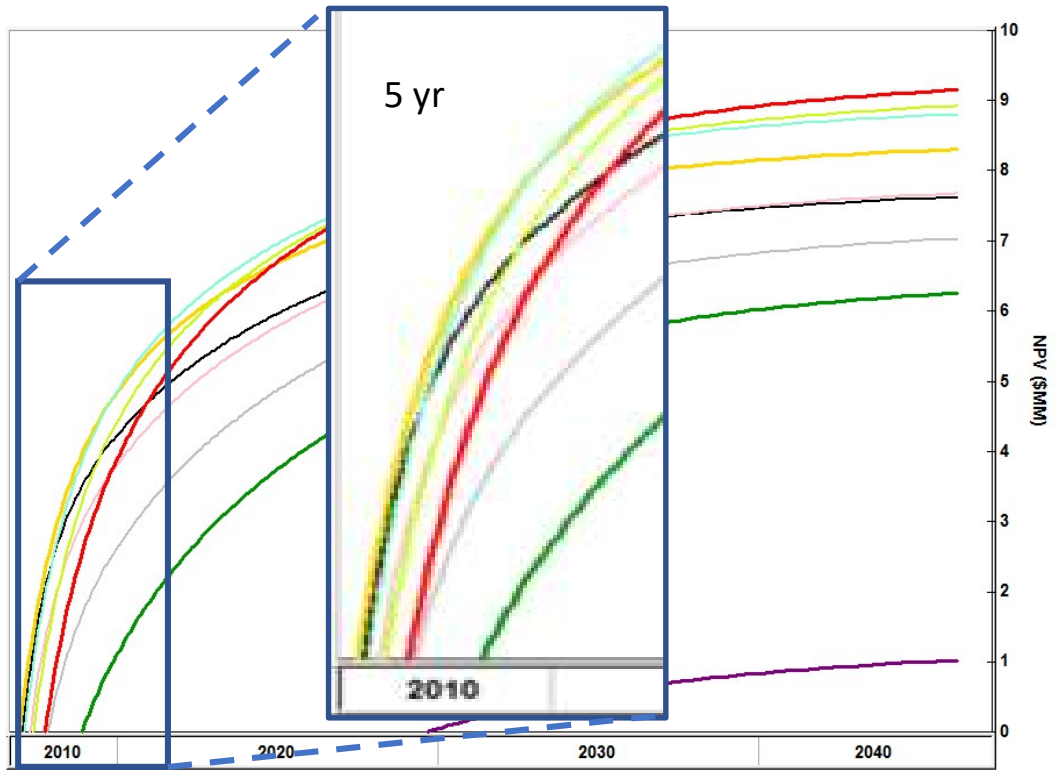
SPE 185064 • Practical Completion Design Optimization in the Powder River Basin• David Anderson

Completion Compartmentalization- Stage Spacing

Montney Example (2015)
Cost - $2300/t
Oil price - $40

Combined optimization of stage spacing and treatment design

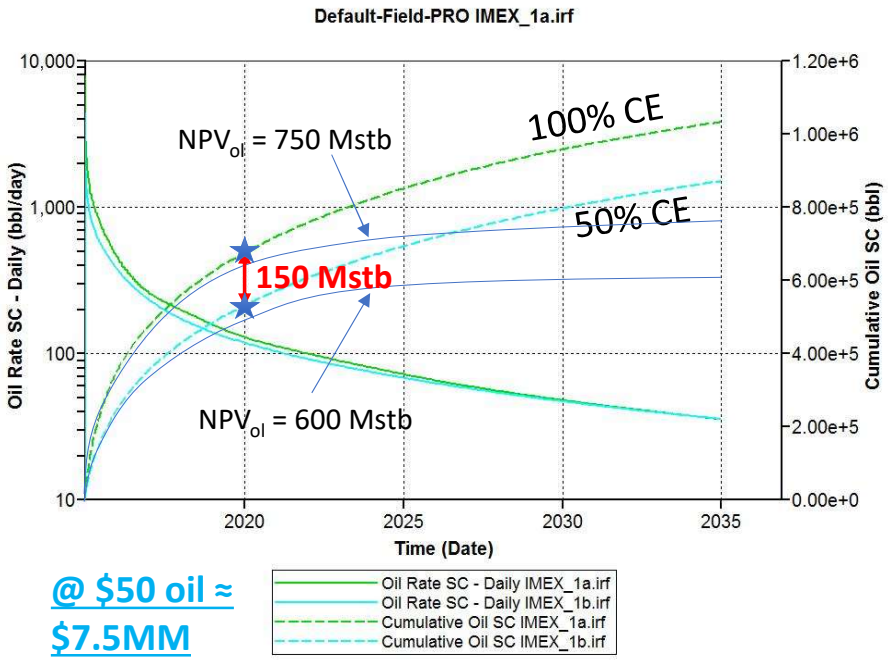
Timeframe is also important



150 ft / 80 t
150 ft / 60 t
150 ft / 45 t
150 ft / 35 t
100 ft / 35 t
100 ft / 45 t
100 ft / 60 t
100 ft / 80 t
50 ft / 45 t

Impact of Frac Placement Uniformity on Performance

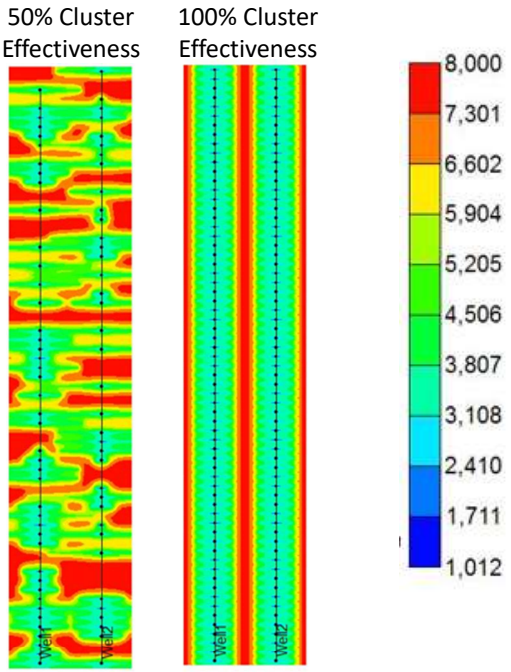
Production Forecasts – 20 years



@ $50 oil ≈ $7.5MM

CE = Cluster effectiveness

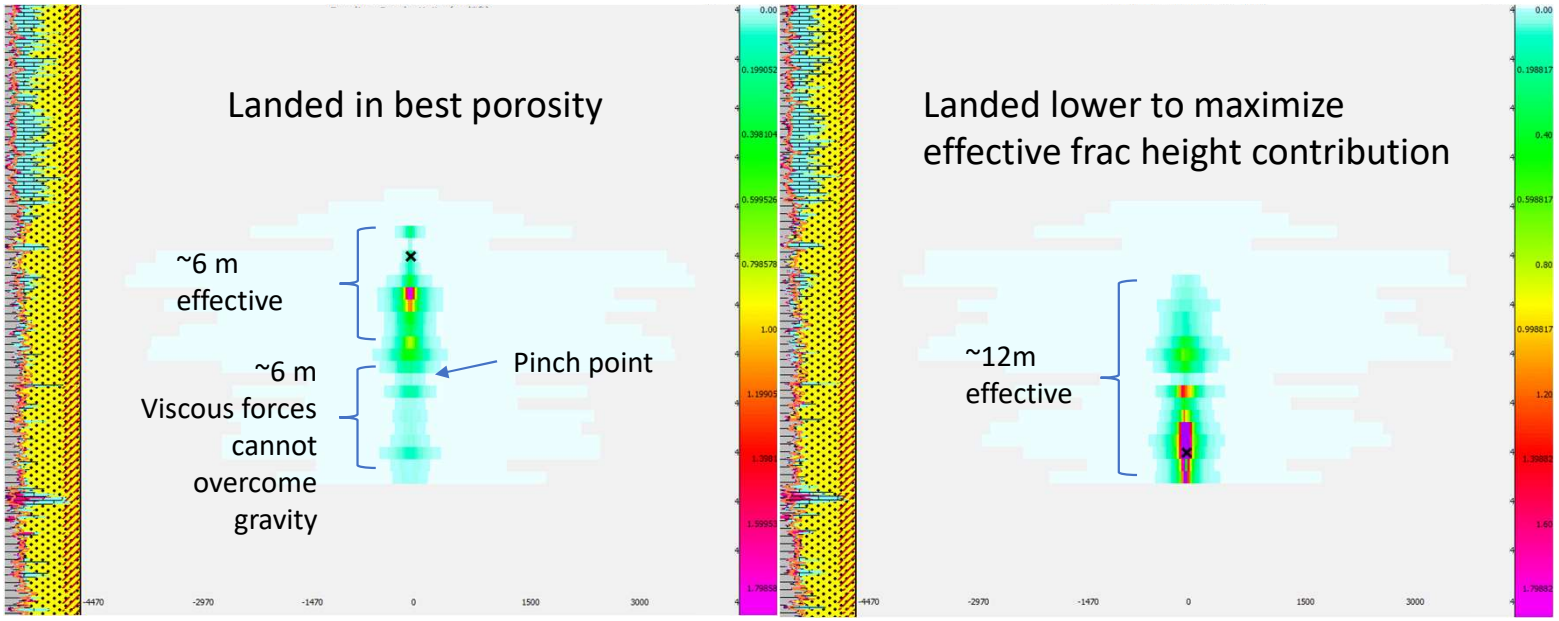
Pressure Map – 2 years



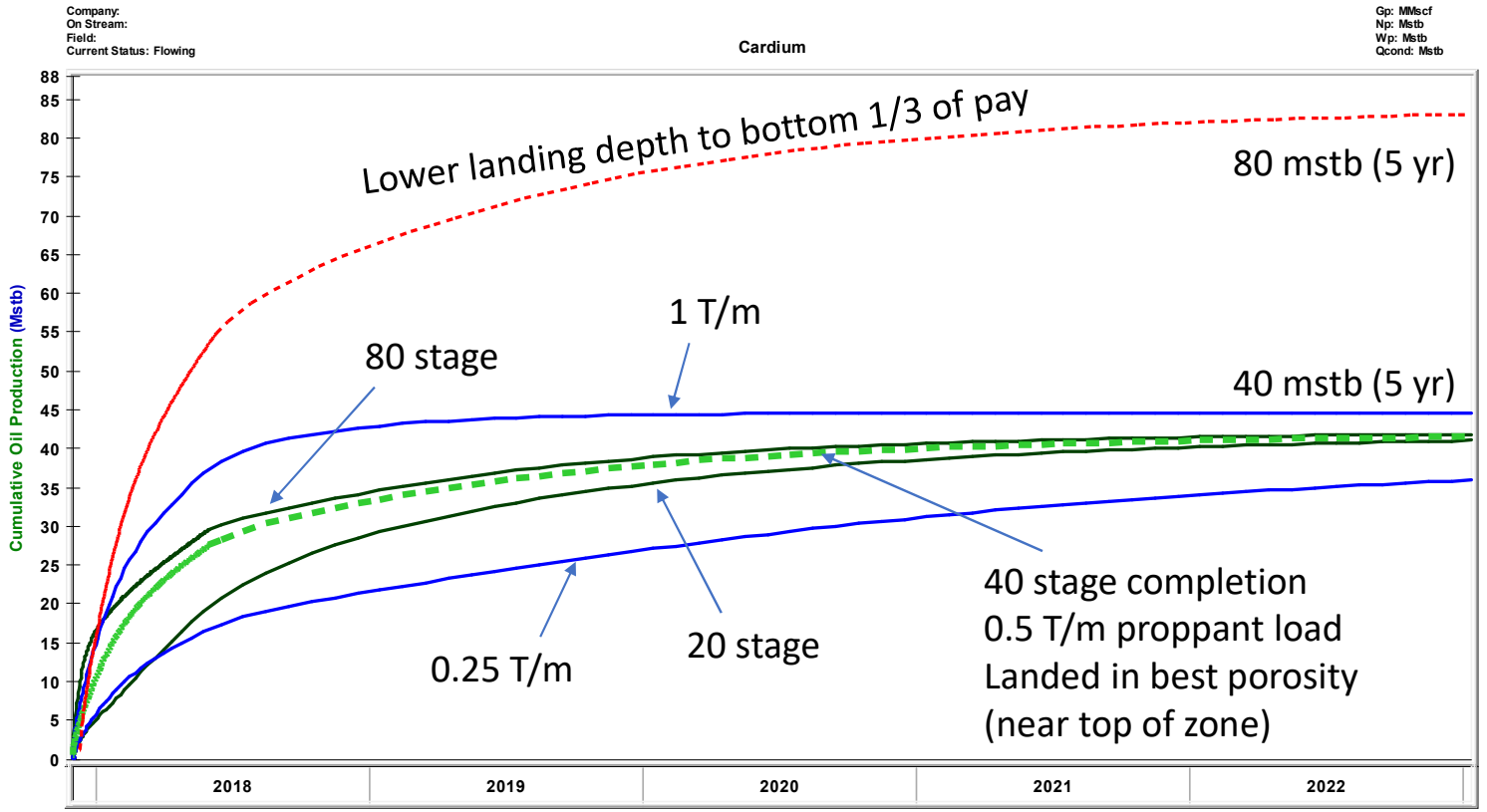
Well Placement- “Make gravity your friend”

An undervalued variable in creating *productive* fracture area

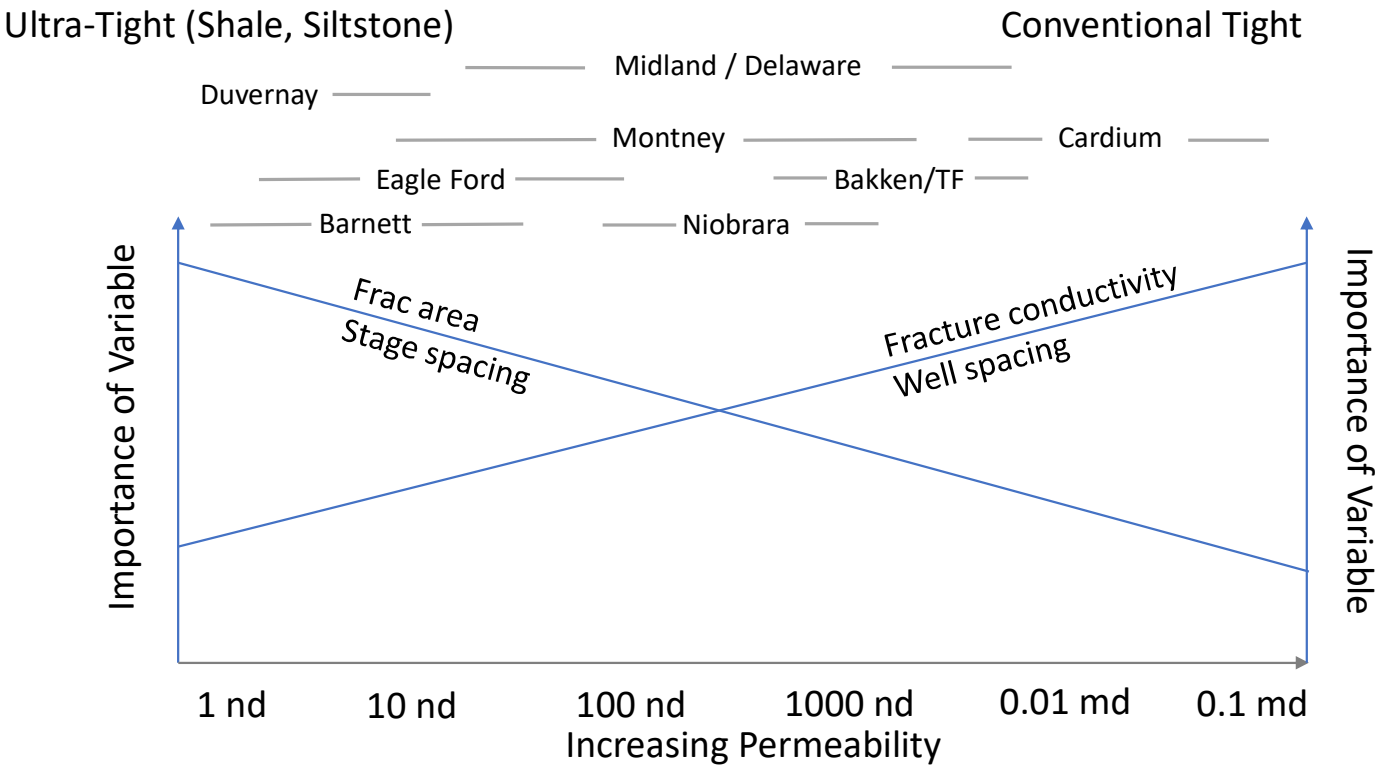
Cardium Example



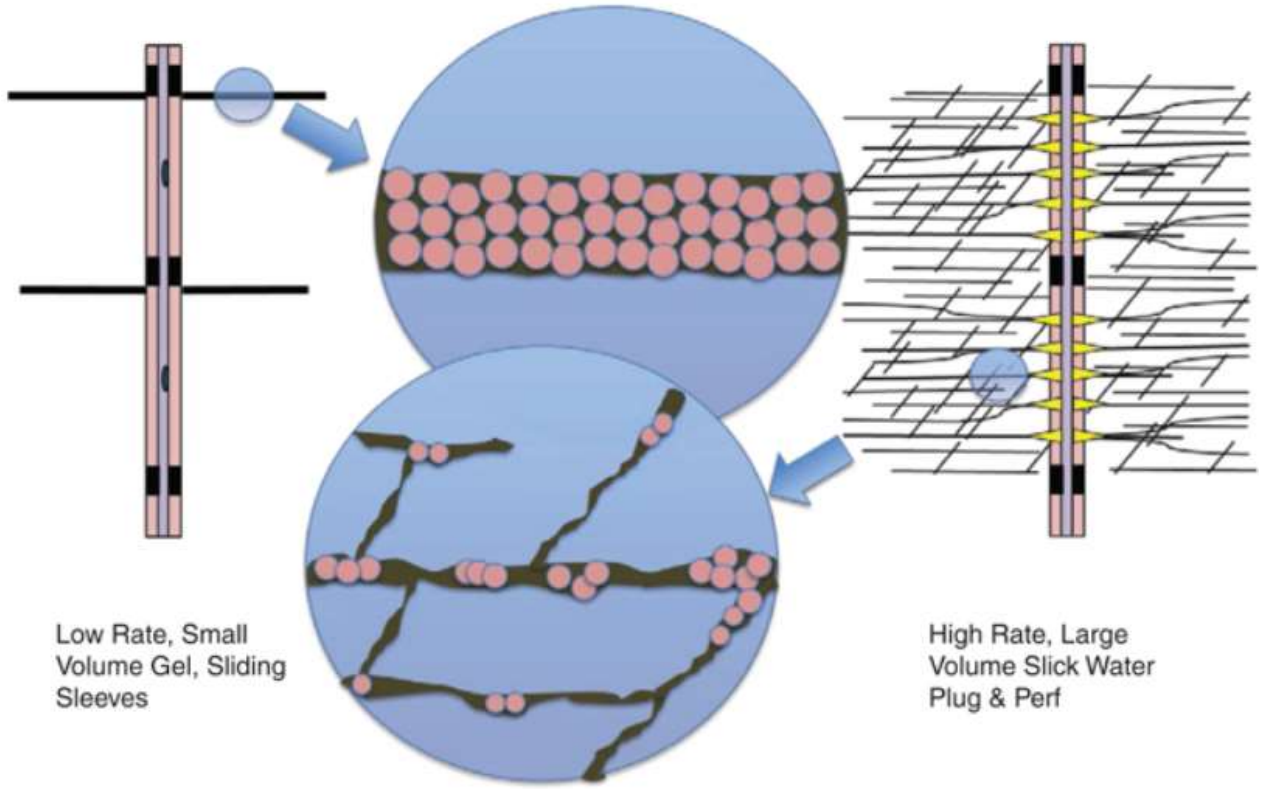
Cardium Example



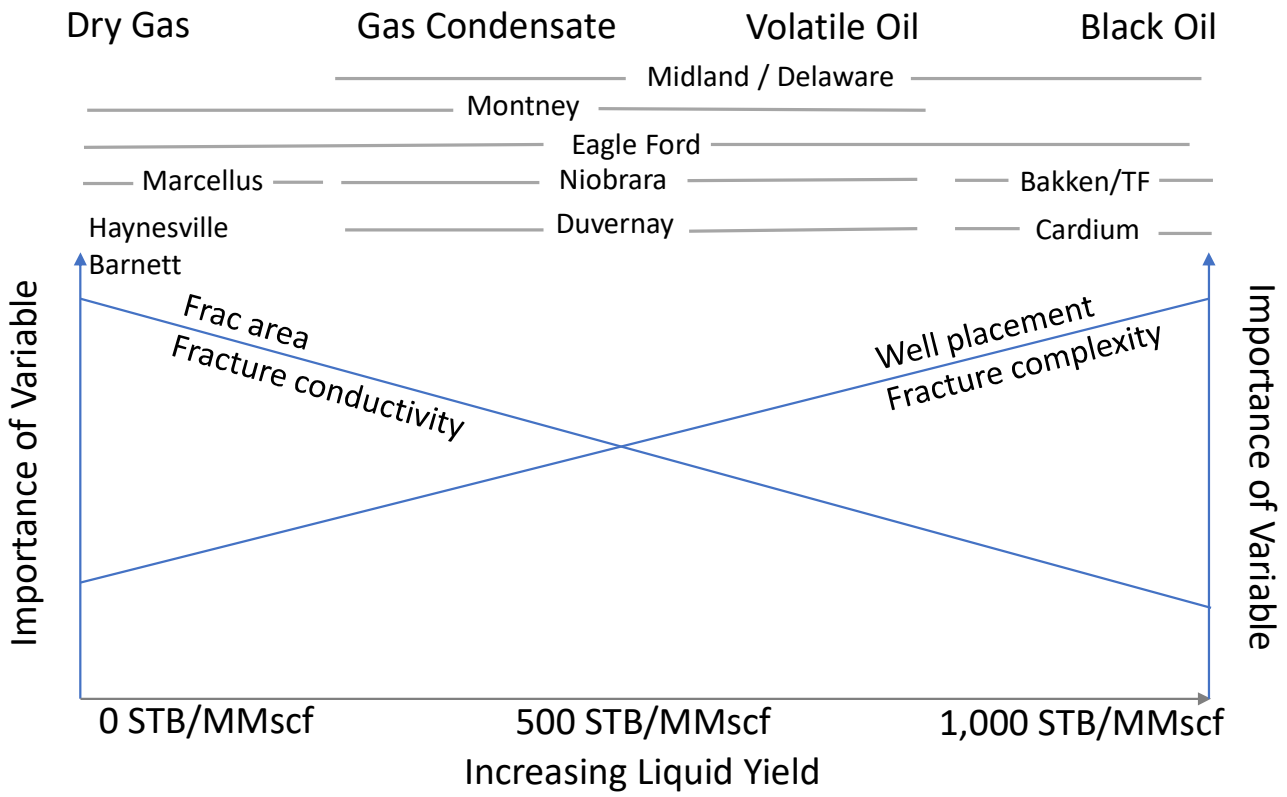
Fit for Purpose Completions – Impact of Permeability on Completion Considerations



Fracture Conductivity versus Fracture Area



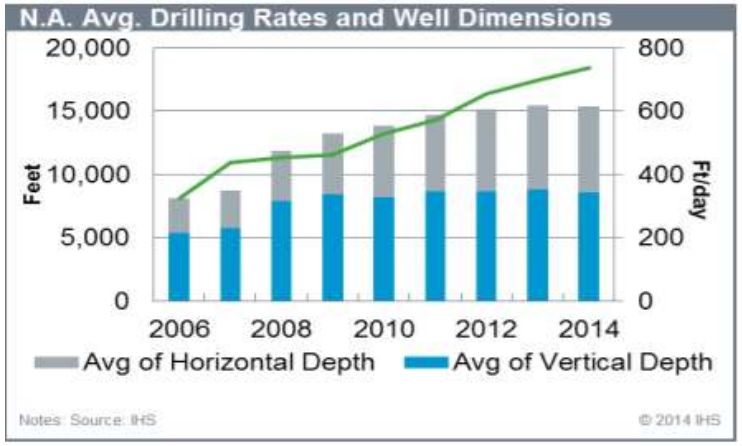
Fit for Purpose Completions – Impact of Reservoir Fluid on Completion Considerations



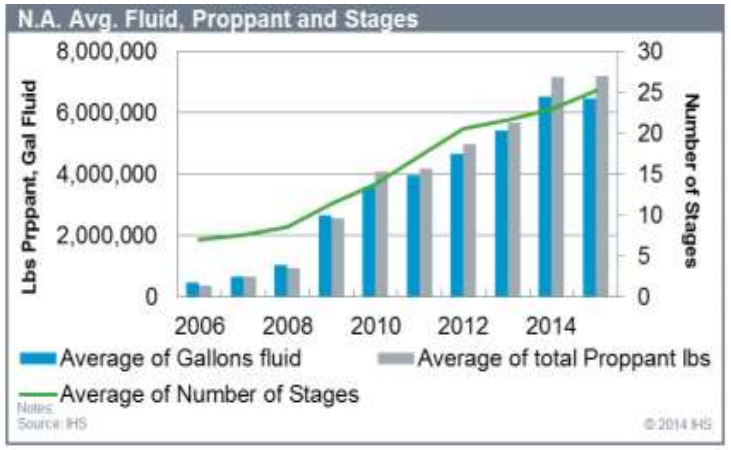
Completion Trends in US and Canada

Drilling and Completion Trends (2006-2016)

Drilling Statistics



Completion Statistics



- Average drilling efficiency (ft/day) has more than doubled (2.5X)
- Average lateral lengths have increased from 2,500 to 7,000 ft
- Average stage counts have increased from 5 to 25
- Average proppant loads have increased from 200,000 to 7,000,000 lbs
- Average treatment intensity has increased from 80 to 1,000 lbs/ft

Pushing the Limits – Well Design & Frac Intensity

Purple Hayes: Eclipse Resources Drills Well with an 18,544 ft Lateral in the Utica; Nine Energy Service Completes a 124-Stage Plug and Perf Frac on the Well

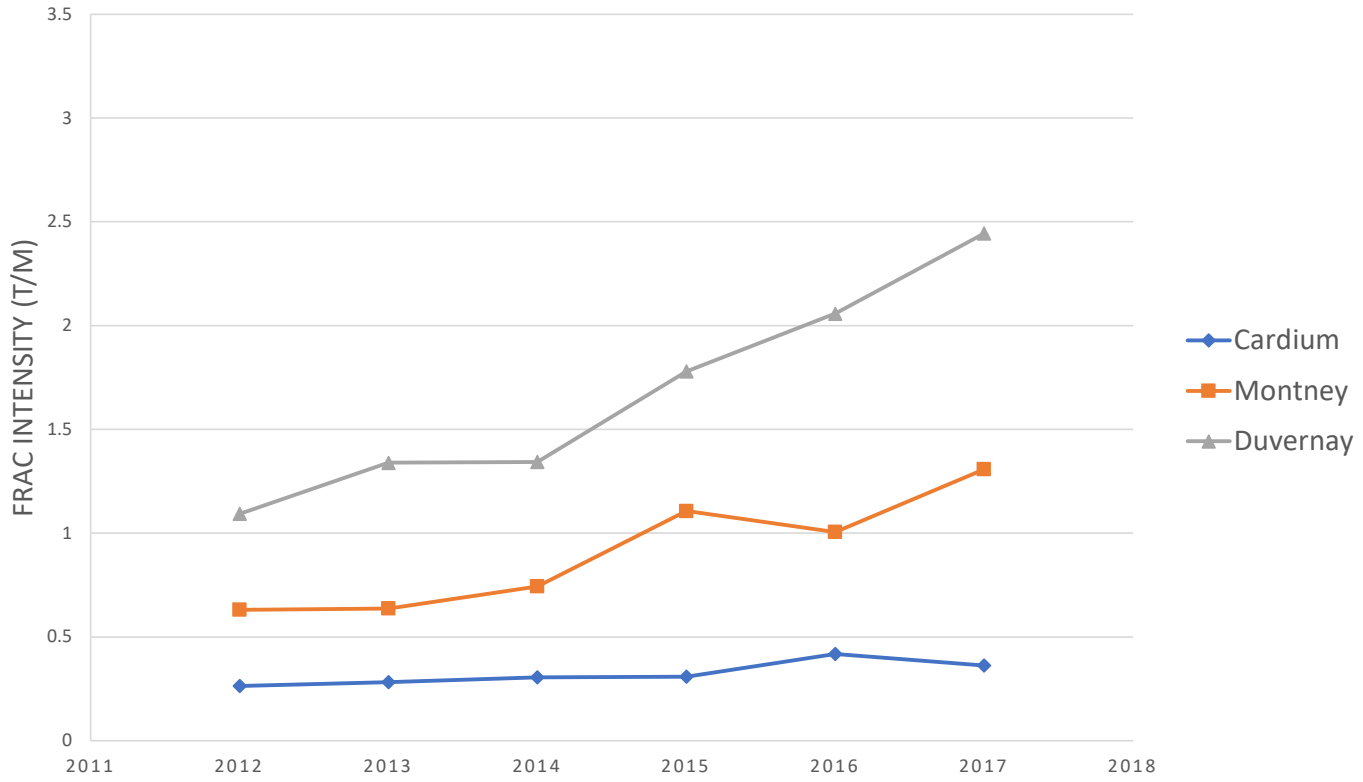
"In drilling the Purple Hayes well to a completed lateral length of 18,544 feet, remarkably, in just 18 days…"

54 Million Pounds of Frac Sand for One Well?

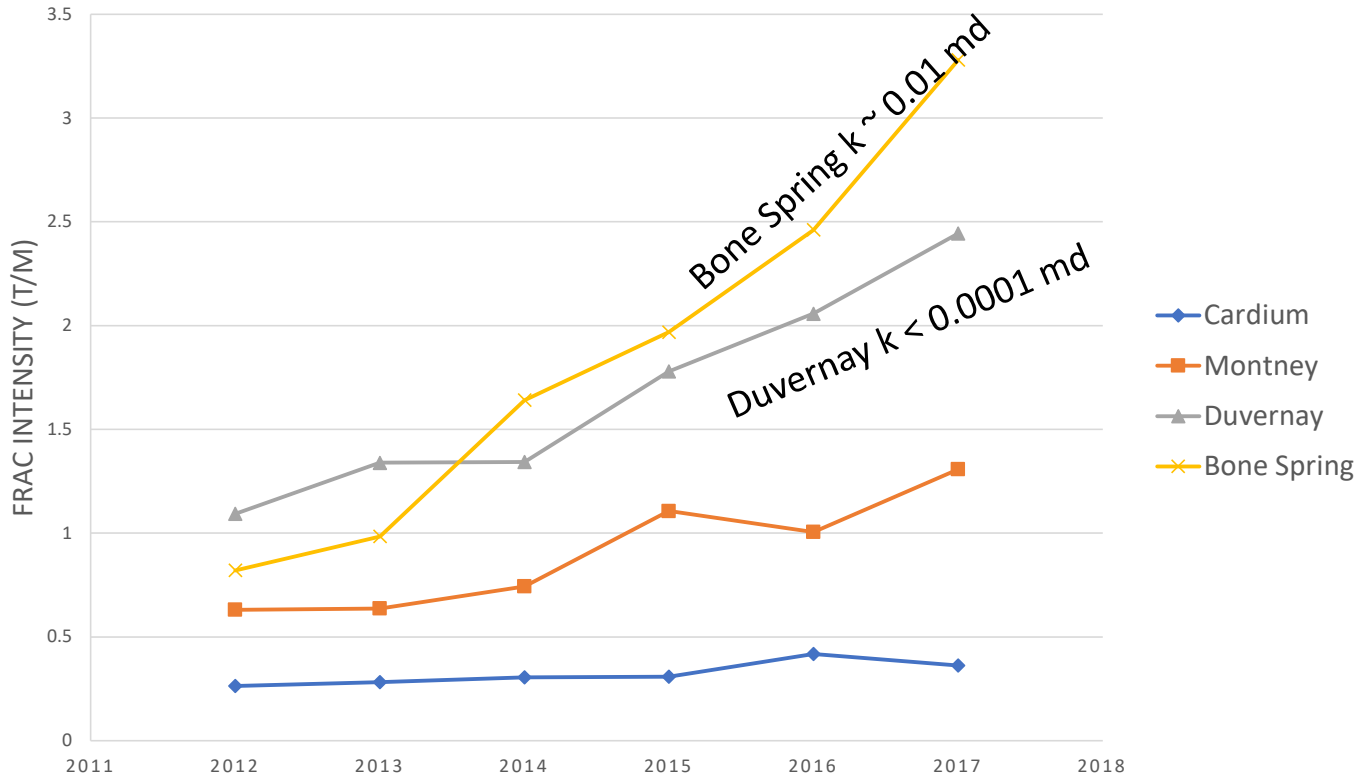
Devon Energy completed one well in the STACK (Kingfisher county) using over 5,000 pounds per lateral foot of 100 mesh and 40/70 frac sand.

Are we optimizing or overcapitalizing?

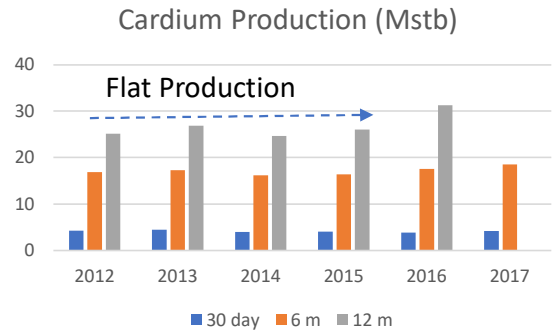
Canadian Completion Trends- Cardium, Montney, Duvernay

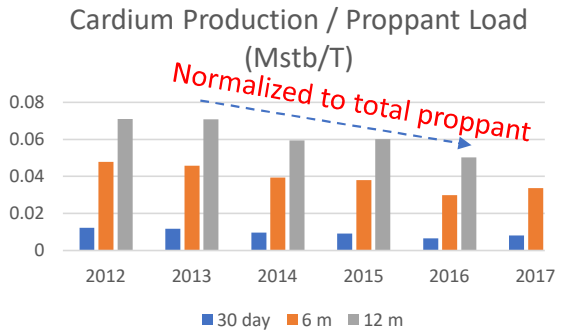


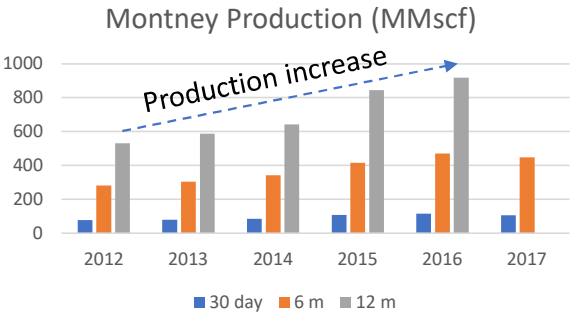
Canadian Completion Trends – Compare with US Example

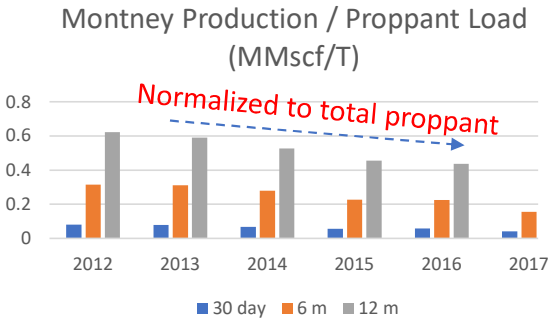


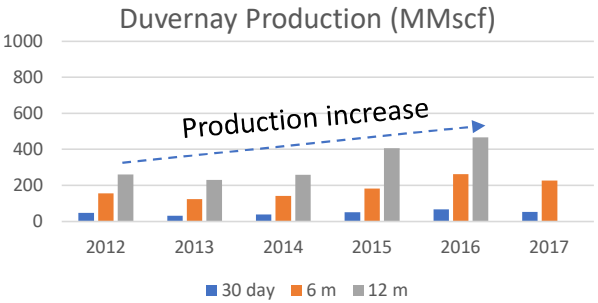
Production Trends- Cardium, Montney, Duvernay

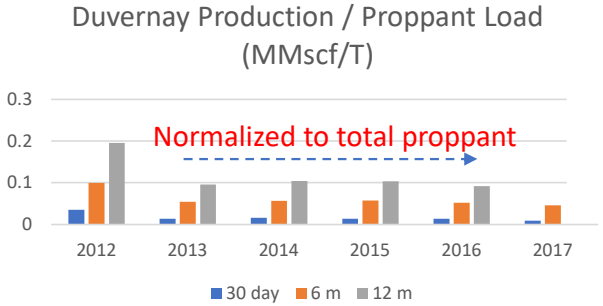




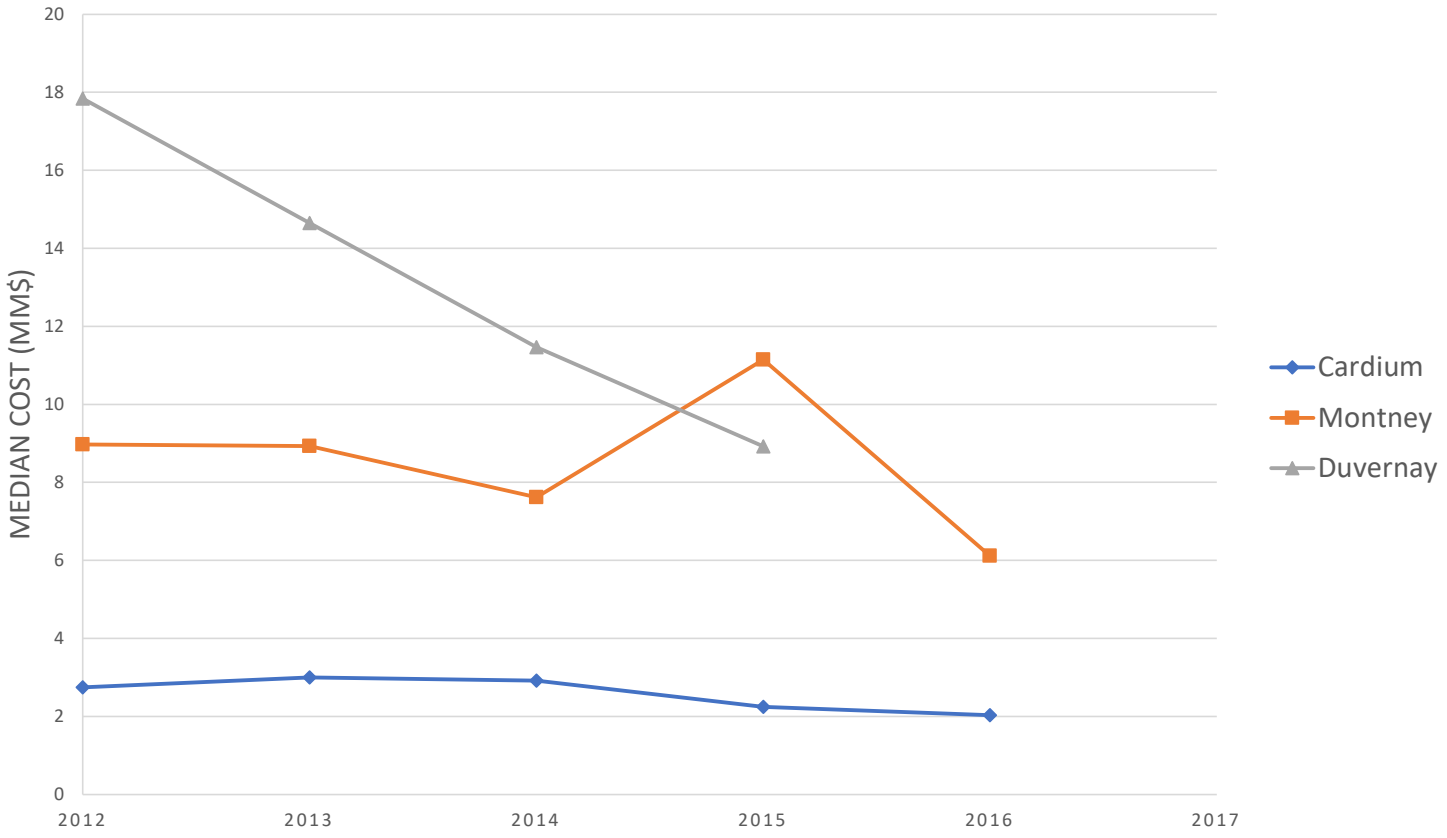




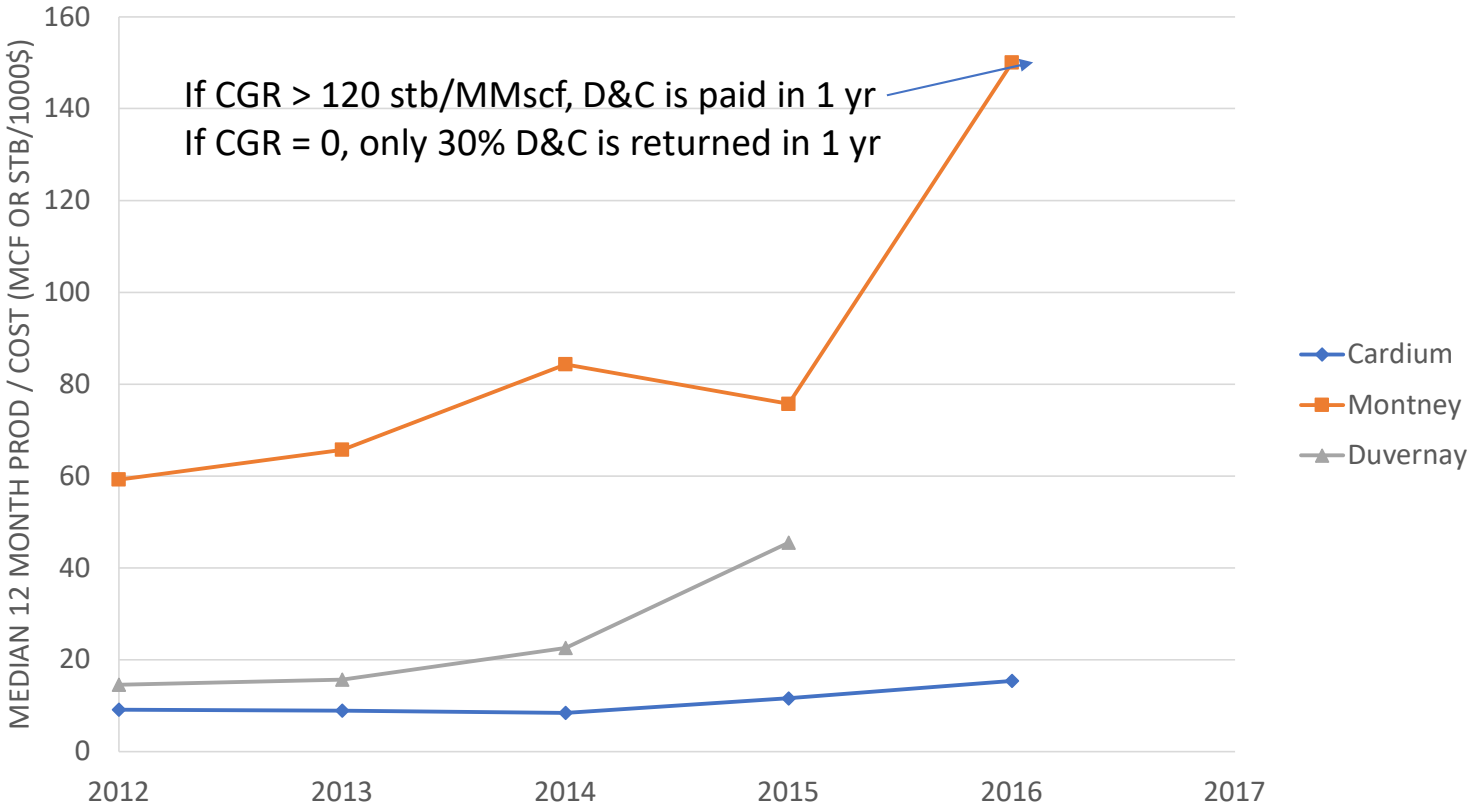




D&C Cost- Cardium, Montney, Duvernay



Cost Normalized Production- Cardium, Montney, Duvernay



Light tight oil (Bakken)– Optimum Completion Strategies

- 0.001 - 0.5 md permeability: Maximizing frac length and stage density are not critical considerations
- Thin pay zone – target landing depth is critical
- Depleted reservoir pressure and GOR breakout are well performance killers

- Optimum completion strategies
  - Landing depth – land in bottom 1/3 of pay zone
  - “Surgical” frac placement is critical for drilling infill wells
  - Sand control is critical – pinpoint completion
  - *Some operators are significantly overcapitalized (true in Can and US)*

Shale oil (EF, Wolfcamp)– Optimum Completion Strategies

- 0.0001 – 0.001 md permeability: Maximizing frac area and density are critical to well performance
- Very thick gross pay interval ~100 m
- Rich gas condensate / volatile oil areas are most prolific- look for 100 stb/MMscf or higher

- Optimum completion strategies
  - Stacked lateral development opportunities (superpad)
  - Maximize effective frac height
  - Maximize treatment volume
  - *Many operators overdesign for conductivity and underdesign for frac area*

Final Thoughts…

- Completions are ***not*** one size fits all
- Reservoirs don’t care about care about changes in market conditions and costs
- What is perceived as value by the market is not always intrinsic value

Questions?