Society of Petroleum Engineers

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Strategies to Optimize Resources Recovery

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Quote for the Day...

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"...success has many fathers, but failure is an orphan..."

Tacitus, Agricola ~ 98 BC

"… an old proverb, but today we have DNA analysis…"

Unconventional Resources E&P Symposium

Vaca Muerta Portfolio

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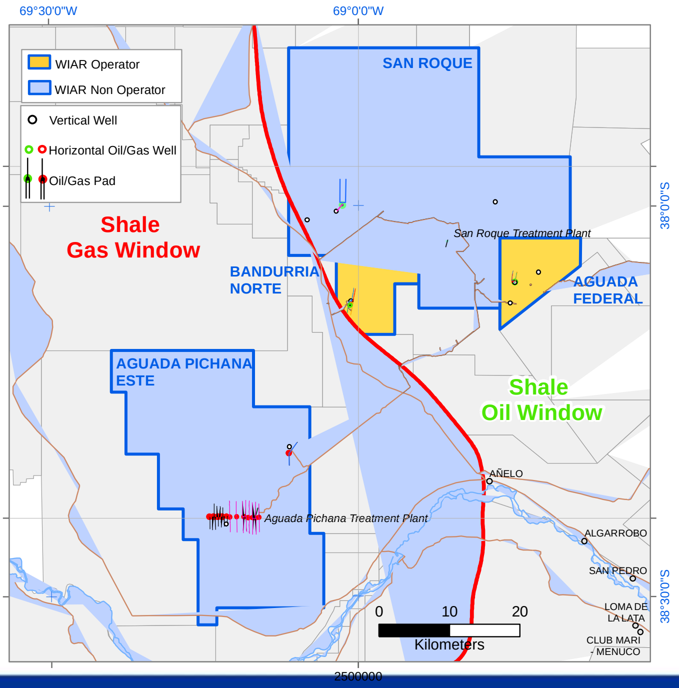


623 km² net shale acreage
>1,000 MMboe Contingent Resources

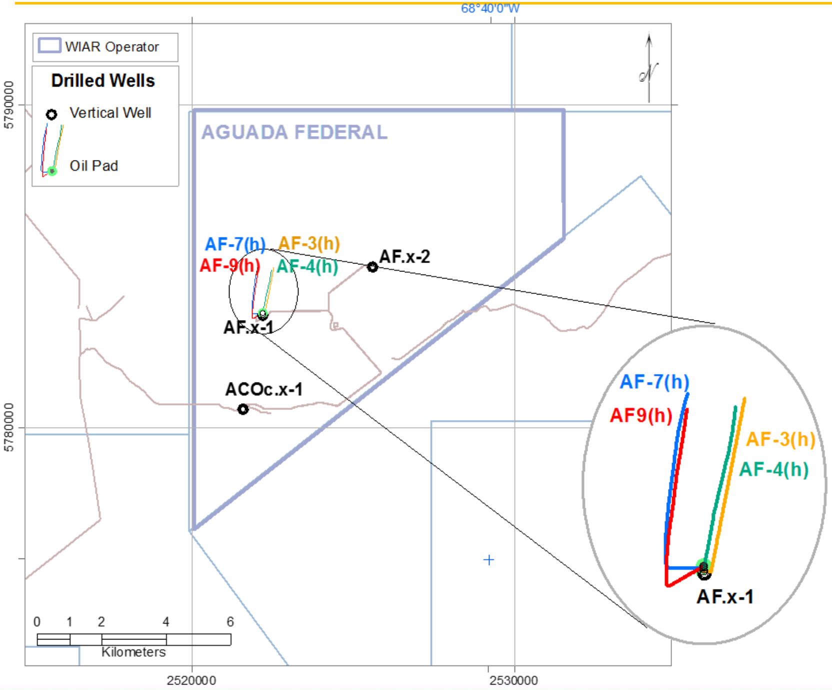
AF	SR	AP	BN
Op	Non-Op	Non-Op	Op
97 km²	1,040 km²	761 km²	107 km²
90 % WI	24.71 % WI	22.50 % WI	100 % WI

~40 Wells drilled
23 shale gas
17 shale oil

~12 Wells producing
6 shale gas
6 shale oil

299 Mbbl oil
226 MMm³ gas
Produced

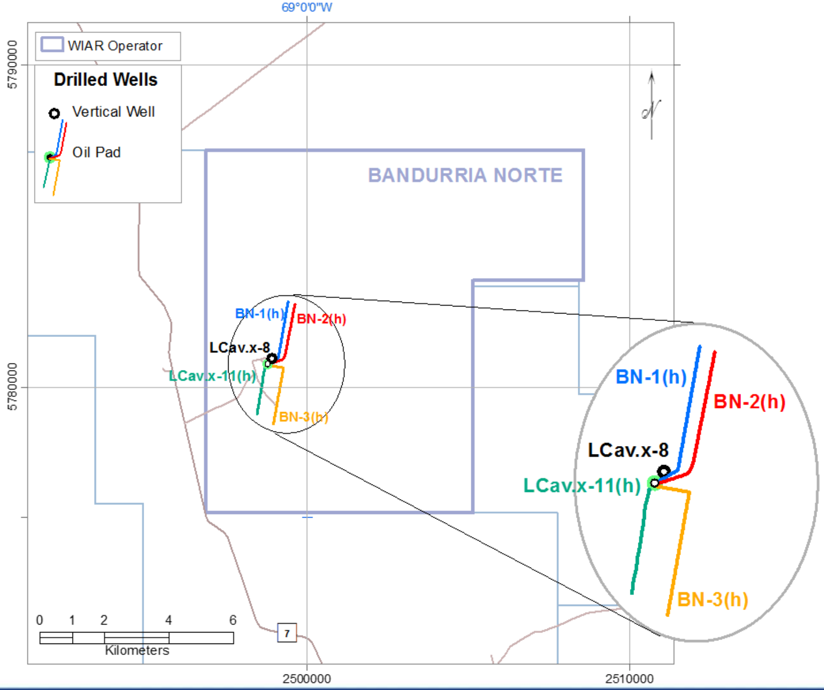
Aguada Federal – Key Facts



Licence Details

- 35-year unconventional exploitation licence granted in December 2015 by Decree 128/15
- Area : 97 km^2
- 3 vertical wells drilled and completed
- Pilot phase 2017-2018: 3 horizontal wells (1,000 m lateral drain)
- 4 horizontal + 1 vertical wells on production, 2 vertical wells shut in
- API gravity of 42° GOR 130 m^3/m^3
- Second pilot planned for 1Q2019

Bandurria Norte – Key Facts



Licence Details

- 35-year unconventional exploitation licence granted in July 2015 by Decree 1542/15
- Area : 107 km^2
- 2 Technology wells drilled and completed
- Pilot phase 2017-2018: 3 horizontal wells (1,500 m lateral drain)
- 4 horizontal wells on production, 1 vertical well shut in
- API gravity of 52° GOR 550 m^3/m^3

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Key Enablers & Drivers

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Assuming basic geological conditions are acceptable!

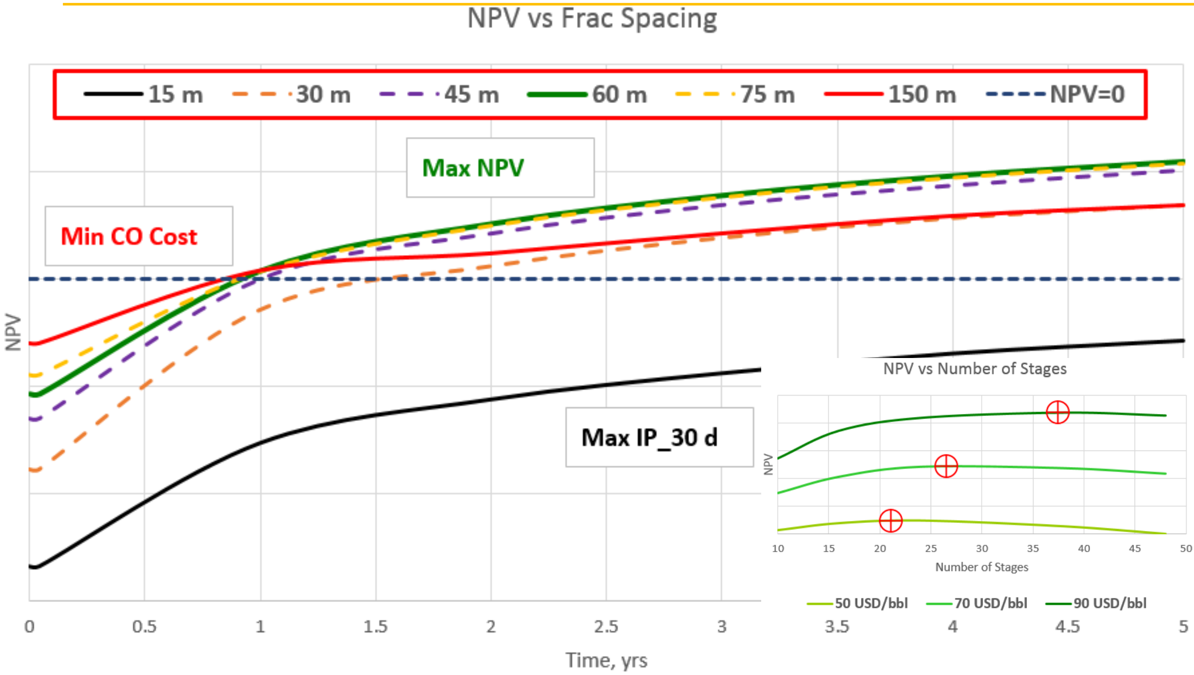
Strategic Decisions

- Landing points
- Well spacing
- Completion

Source: www.dreamtime.com

Main driver: Profitability

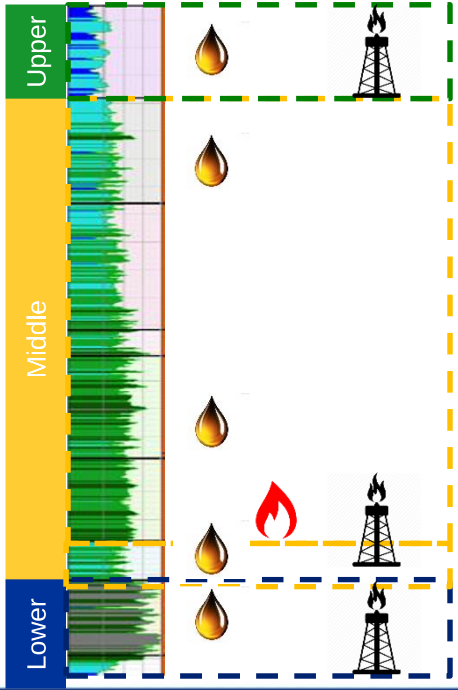
Positive Well Economics = Profitability



Main Guidelines

- Profitability must be the primary driver for successful shale development
- All other aspects underpin primary driver
- Do not focus on highest IP or lowest well cost
- EUR_30 yrs does not make any sense
- Oil and gas price modify NPVs so optimization is a never-ending exercise
- Most of the well recovery should occur during the first 3 to 5 yrs. Economics must be run in that timeframe. If actual cum production is not behaving in that way, think twice why!

Landing Points (from Public Sources)



Facts

- VM provides multiple zones that produce hydrocarbons. Not all are of the same quality. There are stacked pay opportunities (potential different benches)
- Lateral variability has been observed in VM so it can be applicable for one operator but may not be for another
- Same happens in terms of vertical variability
- Oil and gas are main targets but some zones produces with a high water cut

Guidelines

- Harvest first the low hanging fruit!
- Identify isolated reservoirs. Depletion may kill you! Define reservoir compartments or "tanks"
- Assess and define well spacing (vertical and horizontal spacing)
- Drill and complete those isolated compartments alone so you can take advantage of initial reservoir pressure. Measure pressure preferentially at downhole conditions

Icons source: www.psdgraphics.com; www.iconsplace.com; www.iconfinder.com

Well Spacing – Assessment Tools

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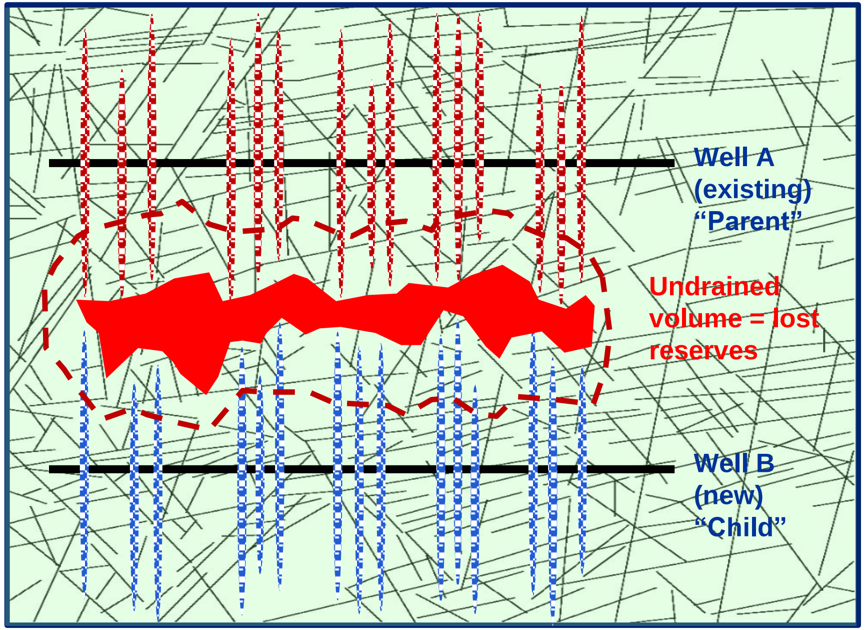

Facts

- Wells do not drain beyond stimulated volume, but not all is effective. Bear in mind available energy to move fluids
- Fracture spacing, frac height and cluster efficiency are key to maximize reservoir contact

Tools…not all

- Tracers (chemical, radioactive, DNA)
- Pressure monitoring (preferentially downhole sensors)
- Micro-seismic mapping. 4D seismic
- Frac hits (not on purpose!)
- Well testing (interference tests)
- Production monitoring
- Fiber optics

Frac Hits = Well to Well Communication

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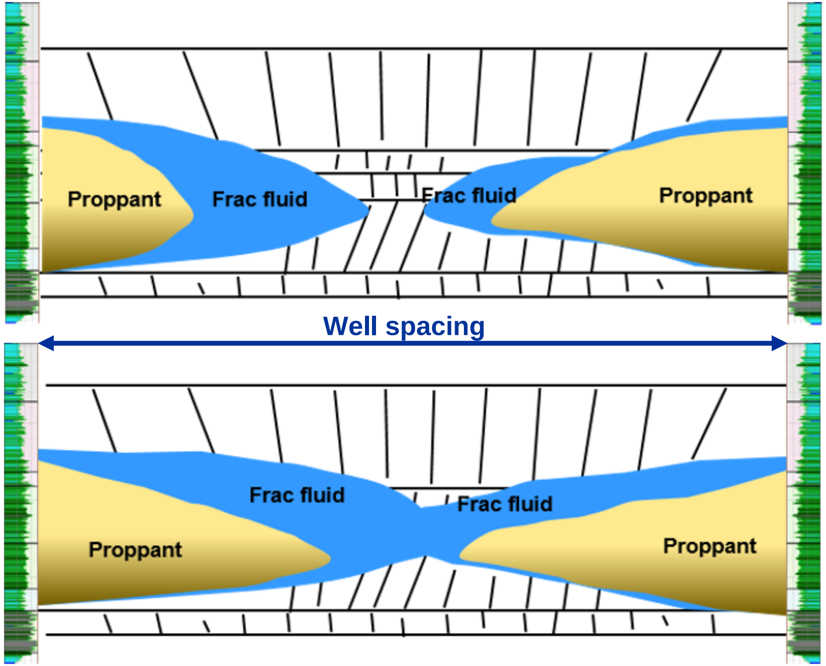
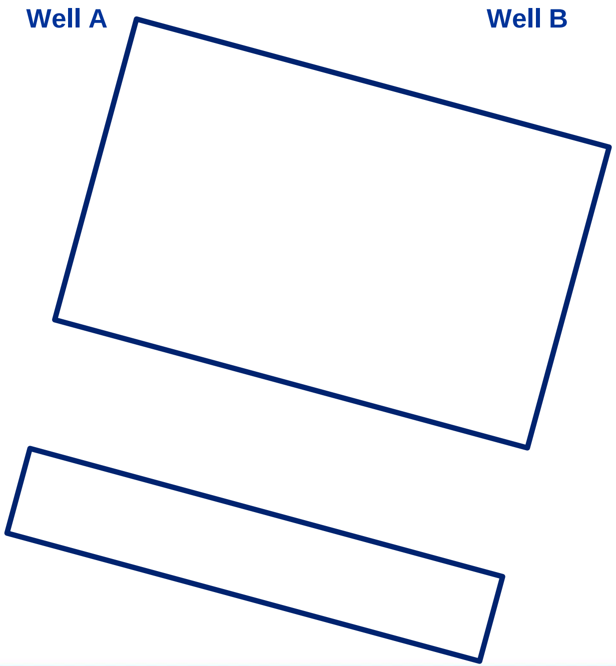


Frac hits as proxies for well spacing

- A frac hit is a well to well communication established while hydraulic fracturing. Good or bad?
- No frac hits might indicate too wide, well to well spacing
- If wells communicate only while fracturing it is a good sign in terms of well spacing still the optimum needs to be fine tuned
- If communication happens after fracturing during production it is a bad sign and indicates a wider spacing is required
- If you change your completion and frac design, your well spacing might also change, so do not nail it down as a given for good!
- Integrate results from different tools and disciplines
- Watch for other problems such as killed wells, potential blowouts, mechanical damage to wells, etc. No easy recovery at this point!
- If frac hits improve production in offset wells, they might be good candidates for refracturing. Potential upside!

Well Spacing from Microseimic



Observations – VM wells

- Buried array surface micro-seismic
- Even though well “B” was fractured with frac spacing based on engineered fracs, there are three distinctive micro-seismic clouds
- Micro-seismic events overlap during first frac stages (1 to 6) and potentially during last two. Potential interpretation as interactions. Need to be confirmed with other sources
- Overlap of events within the same well

Results & actions

- For first half of the well, it looks like there is an overlapping of micro-seismic events and potentially well communication
- Remaining half shows room for improvement in terms of well spacing
- Location uncertainties and velocity model were checked to confirm those locations. Errors found but main picture was not altered

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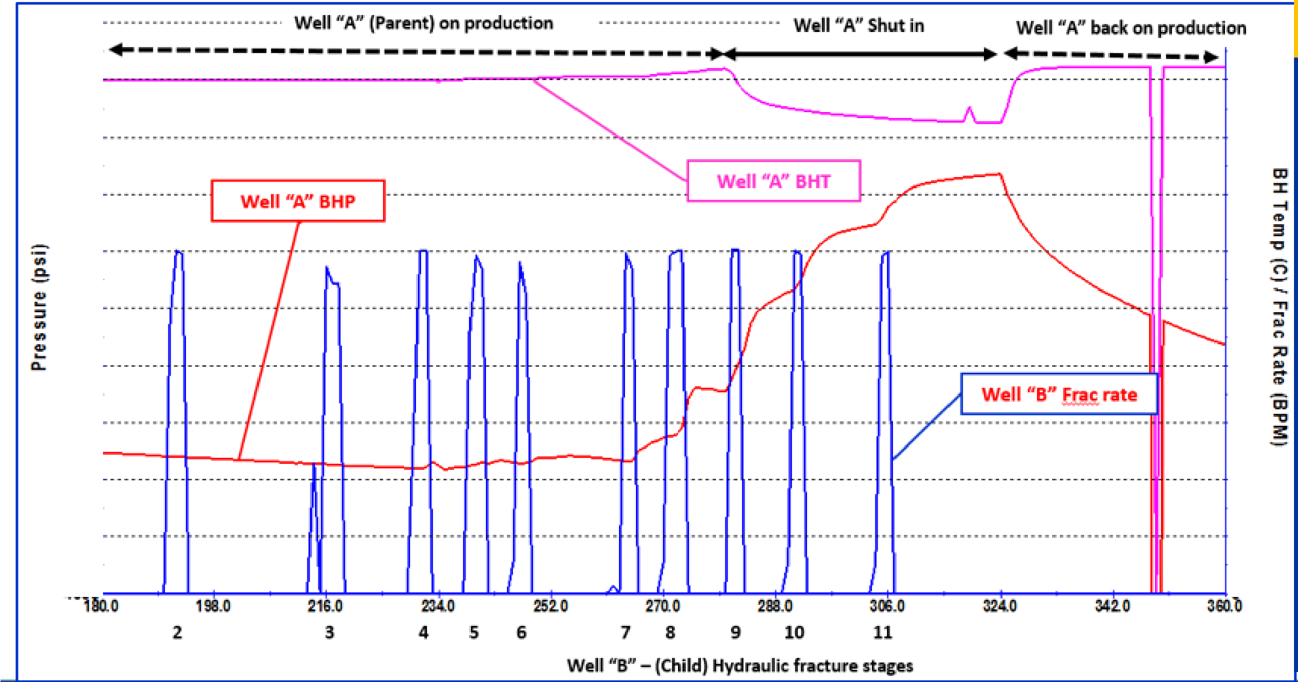
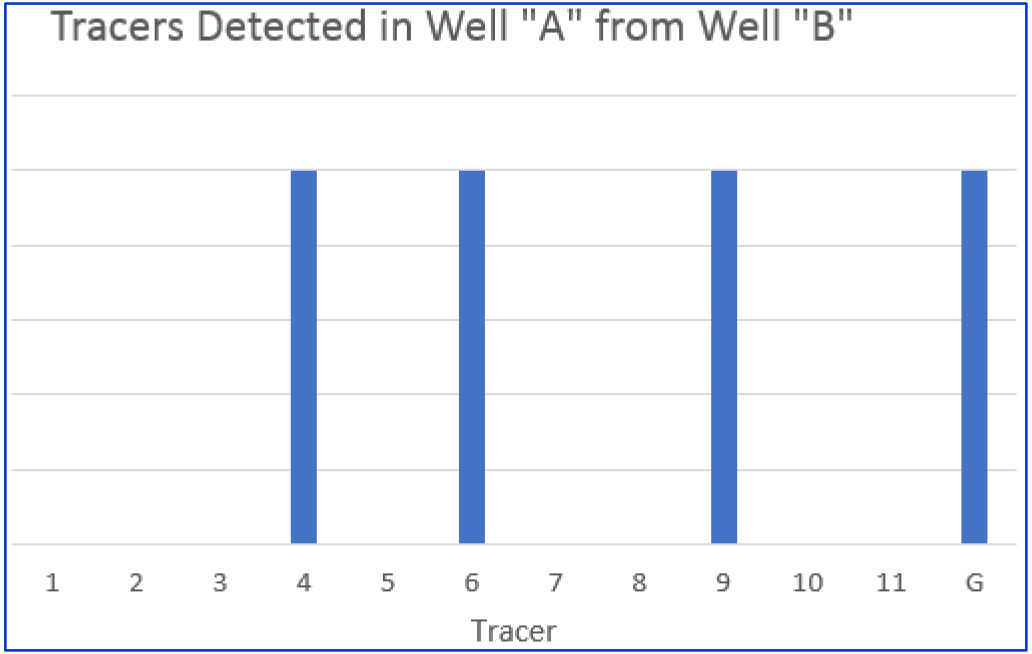
Downhole Pressure Monitoring



Observations

- Two horizontal wells spaced out ~400 m relatively at same depth
- Real time downhole and surface P&T monitoring system
- Initial pressure peak while fracturing stage nº 4
- Abrupt change in pressure increase slope during stages 7, 8 and 9
- Pressure looks more sensitive than temperature
- Longer times between stages mitigates pressure rise
- Pressure continues rising even after finishing frac pumping

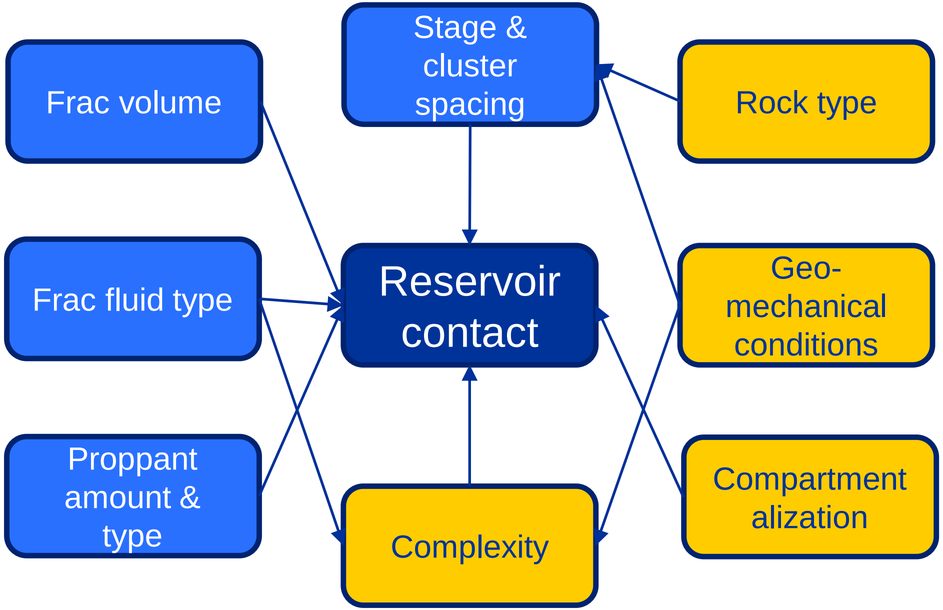
Well Interference – Chemical Tracers



Observations / Results

- Some tracers were detected giving hard evidence that wells were in communication
- Tracer concentration decreased quickly in time with a different rate compared to tracers from the same well indicating that communication was only while fracturing
- Micro-seismic, pressure and tracers show a relative consistent picture with micro-seismic the most optimistic in terms of communication
- Production from both wells has not shown signs of communication when wells are individually shut-in or when both are produced together
- Wells seem to be slightly over spaced but this result should be confirmed with more wells

Completion Strategy – Key Ones



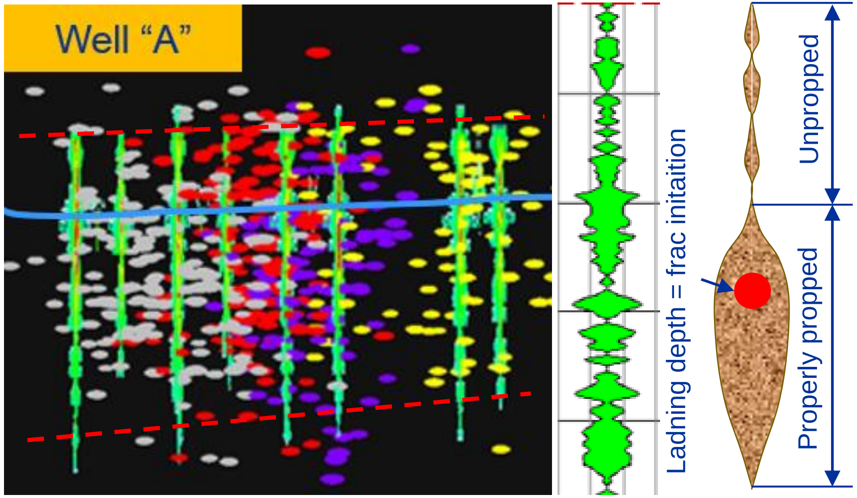
Facts

- Completion related costs account for more than 60 % of total well cost
- As permeability decreases, contacting more reservoir is the only way to produce more fluids
- Still you need enough energy and fluids mobility to start moving fluids and transport them to the well
- Existing depleted zones are your enemy!

Guidelines

- Every time you decide to change think mainly in terms of profitability of the well and the impact on well performance
- Attack only those items that really impact well profitability! It seems basic but not all operators are following this simple rule. Plenty of examples in US

Frac Height



Frac production performance → Frac initiation → Well landing depth

Why is it important?

- The most important variable in reservoir contact. Probably more important than length. Many times undervalued
- The point where the fracture is initiated will govern final frac height
- Proppant distribution in height is not homogeneous, settling occurs mainly if low proppant concentration and slick water are used

Guidelines

- Well performance instead of reservoir properties must govern the decision on where to initiate the fracture. Frac growth sensitivity analysis with a solid geo-mechanics model will help
- Gravity can be a friend or foe in terms of production and proppant settling! Take advantage of it
- Identify frac barriers. These will be the reservoir limits in height
- Aim to land wells in the lower portion of the reservoir

Frac Conductivity – Do we Really Need it?

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$$C_{fd} = \frac{k_f * wf}{k_{res} * xf}$$

We can impact them!

Frac design	
$k_f * w_f$ = 10 md-ft	x_f = 100 ft (~30 m)

Tight reservoir (k= 0.1 md)	
C_{fd} = 1	Improve C_{fd}

Shale reservoir (k= 0.0001 md)	
C_{fd} = 1000	Overdesigned. Optimize!

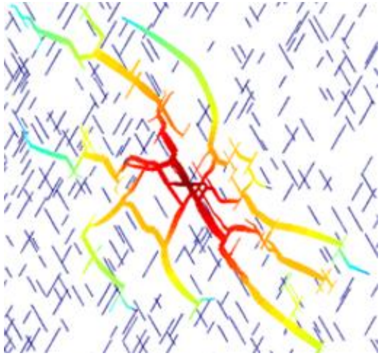
Facts

- A fracture to be effective needs to have a conductivity higher than the reservoir. C_{fd} is a dimensionless term to account for it
- There is an optimum. Too high means we are wasting our capital. Too low means we have room for improvement in terms of production but we need to add some capital
- C_{fd} degrades with time. Sad…but true! Hydraulic fractures do not last forever! Impact on well spacing

Guidelines

- Proppant selection is not only a technical decision, it is mainly driven by profitability. The way we allocate capital will dictate our results
- Work on those variables that drive production performance
- Have a clear strategy about your business, are you there for the long term? Or just want to show potential and sell the asset?

Complexity – Always Beneficial?



Source: Zhang, et al, 2015

Gas: if no natural fissures, still gas diffusion is a strong mechanism for gas transport thru the matrix

Oil: due to its viscosity, it will only flow thru fissures (open-natural or induced)

Facts

- Frac complexity is beneficial to production performance in all reservoirs. Multiplier of reservoir contact. From 2D to 3D dimension
- It is a dominant driver in tight oil saturated reservoirs
- Less important in gas saturated reservoirs
- Complexity directly linked to the presence of natural fissures but this condition is necessary but not sufficient
- Geo-mechanical conditions set the trigger for their activation
- There is not too much we can do to manage the process

Guidelines

- If possible, use frac fluids with low viscosity and fine grained proppants. Very common in gas saturated reservoirs
- Increase frac stage density or intensity

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High Density or Intensity Completions

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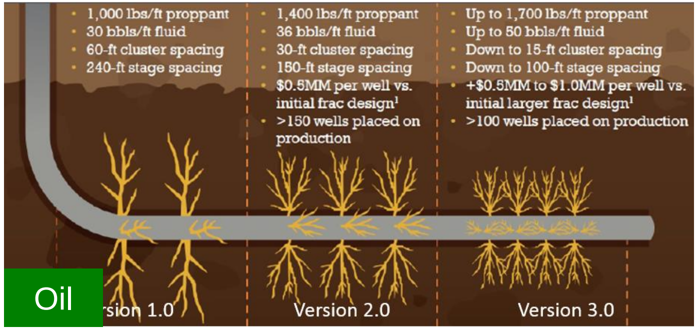
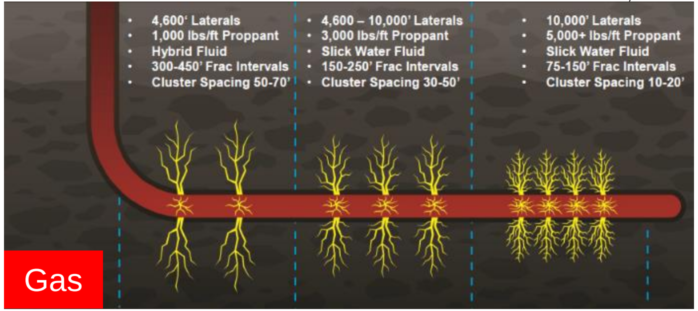


Source: Pioneer Resources, 2017

Source: Goodrich Petroleum, 2017



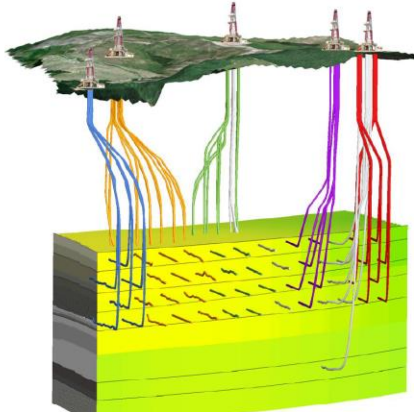
Facts / Observations

- Difficult to bring fluids from regions relatively far away from wellbore (< 30 m)
- Hard to create long uniform and conductive fracture from every single cluster
- Industry is moving to tighter cluster spacing pumping more proppant and fluid and faster pumping rate per foot. Why? Is not stress shadowing an issue?

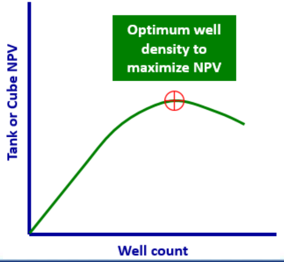
Guidelines

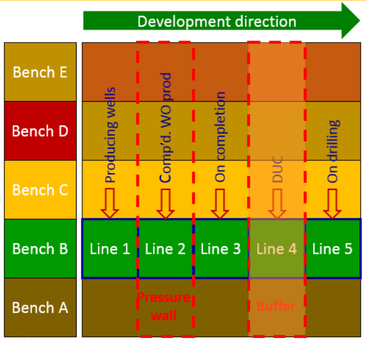
- Shorter clusters provide more effective fractures resulting in an enhanced stimulated volume close to the wellbore = High Density or Intensity Completions. Common to observe 15 ft (~5 m) cluster spacing or even less
- Number of clusters / stage must be properly designed to ensure that most take fluid, otherwise reduce them. The larger the number of clusters the lower the efficiency. Use diverters and/or increase fracturing pumping rate to improve it!
- Even though stress shadowing is present, actually it helps with fracture complexity thus increasing reservoir contact (it actually reduces frac length)

Tank or Cube-Style Completions

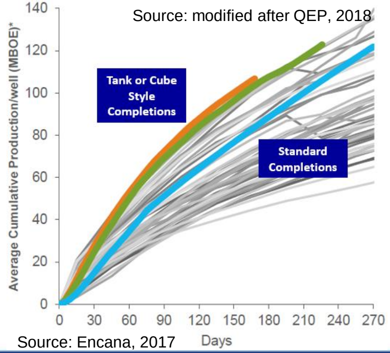


Source: Encana, 2017





Source: modified after QEP, 2018



Source: Encana, 2017

Objectives

- Tailored for full-development of multiple stacked assets from a single above-ground location in a large multi-well pad
- Simultaneous drilling and completion of all wells. In-fill drilling is avoided from the very beginning
- All the wells in the “tank or cube” are completed before any well is put on production to take full advantage of original reservoir pressure. Avoidance of pressure sinks

Above and below the ground benefits

- Minimized footprint. Accelerated learning. Higher equipment and crew utilization. Optimized infrastructure. Integrated planning and logistics
- Optimize resource recovery. Minimize inter-well communication
- Enhanced operational efficiency. Minimize downtime on existing wells
- Lower development costs. Maximize capital efficiency. Improved NPV

Thanks!

…time for questions

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