Challenges and Opportunities in Vaca Muerta

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Poll Question

What geographic region are you from?

Poll Question

What is your discipline?

Poll Question

Who is your employer?

Poll Question

How many years of experience do you have?

Mr. Jorge Ponce is currently the Completion and Stimulation Lead at Wintershall Argentina in the Unconventionals Department.

He earned a degree in Chemical Engineering from National University of Patagonia in Argentina. In addition, he obtained a post degree in Project Management from the University of Belgrano and has attended Manager's training program from the Business School at IAE both in Argentina.

With a strong background and experience in Completions and Stimulations, Jorge has worked in other disciplines including drilling, cementing, production and well testing which allows him to integrate multiple disciplines for wells or field evaluations.

Prior to joining Wintershall, Mr. Ponce had worked for over 20 years at different companies in several positions including BJ Services, Amoco, Pan American Energy, BP and Apache. While working for BP in US, he oversaw a Project focused on applying new completion and stimulation technologies and pushing the limits of existing ones for unconventional reservoirs. As part of the project, he wrote the completion and stimulation handbook for unconventional reservoirs.

Jorge has authored or coauthored several technical papers in national and international publications and he actively participates in technical events and educational institutions. He has given internal and external courses with the sole objective of knowledge dissemination on the application of new technologies. In 2013, he received the SPE South America and Caribbean Region award in Completions Optimization and Production.

Jorge is currently a professor and working on the final project of his post-degree in Unconventional Reservoirs at the Technological Institute of Buenos Aires. He is member of the SPE, IAPG and ASME.

Jorge Ponce
Wintershall
Argentina

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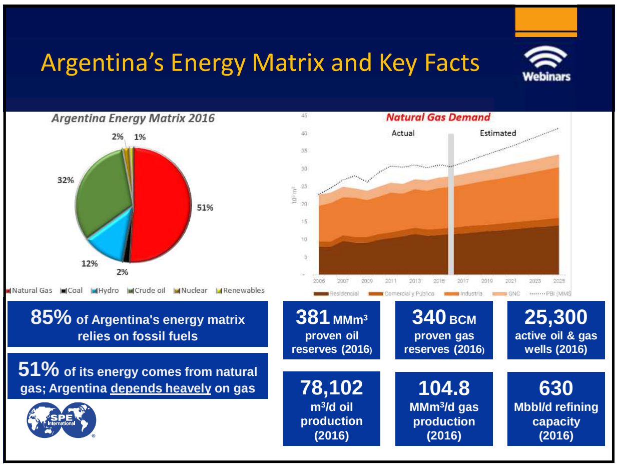
Initial Quote…

"… It's Good fishing in troubled waters…"

Popular proverb


Argentina's Energy Matrix and Key Facts
Webinars
Argentina Energy Matrix 2016
2% 1%
32%
51%
12%
2%
Natural Gas
Coal
Hydro
Crude oil
Nuclear
Renewables
Natural Gas Demand
Actual
Estimated
85% of Argentina's energy matrix relies on fossil fuels
51% of its energy comes from natural gas; Argentina depends heavily on gas
381 MMm³ proven oil reserves (2016)
340 BCM proven gas reserves (2016)
25,300 active oil & gas wells (2016)
78,102 m³/d oil production (2016)
104.8 MMm³/d gas production (2016)
630 Mbbl/d refining capacity (2016)
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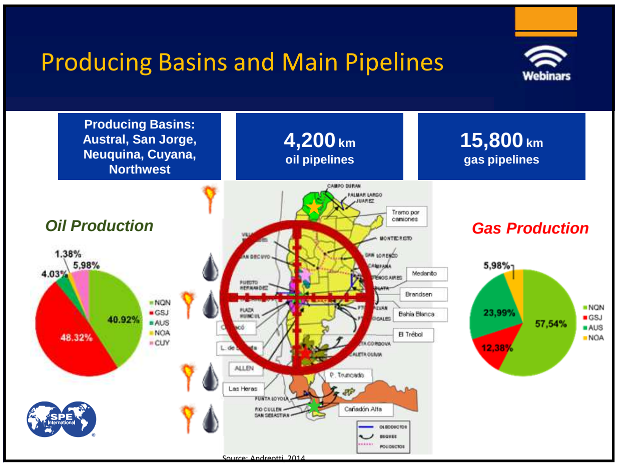
Producing Basins and Main Pipelines
Webinars
Producing Basins: Austral, San Jorge, Neuquina, Cuyana, Northwest
4,200 km oil pipelines
15,800 km gas pipelines
Oil Production
1.38%
4.03%
5.98%
40.92%
48.32%
NQN
GSJ
AUS
NOA
CUY
Gas Production
5,98%
23,99%
57,54%
12,38%
NQN
GSJ
AUS
NOA
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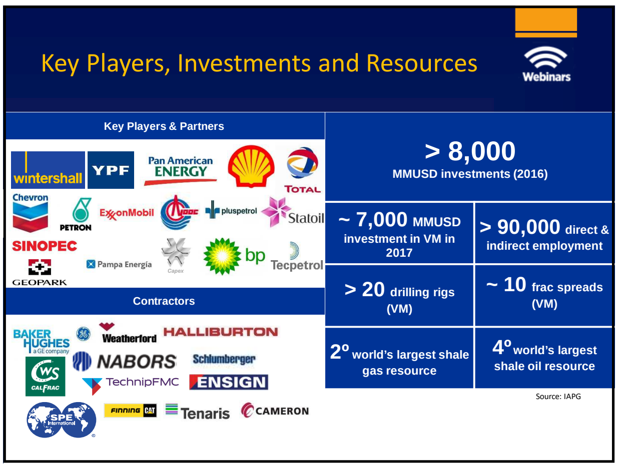
Source: Andreotti, 2014


Key Players, Investments and Resources
Webinars
Key Players & Partners
Contractors
> 8,000 MMUSD investments (2016)
~ 7,000 MMUSD investment in VM in 2017
> 90,000 direct & indirect employment
> 20 drilling rigs (VM)
~ 10 frac spreads (VM)
2° world's largest shale gas resource
4° world's largest shale oil resource
Source: IAPG
SPE International

Critical Factors for Success – Not All!

Sub surface
- ✓ Complexity
- ✓ Geo-mechanics
- ✓ Permeability
- ✓ Reservoir fluids

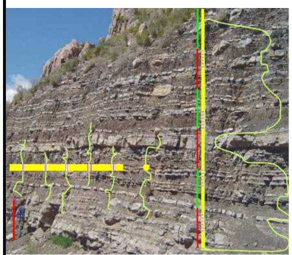
Technological
- ✓ Clustering
- ✓ Monitoring

Political
- ✓ Sorry, I am a technical person. I will try to skip this topic!

Economical
- ✓ Production
- ✓ Development scale
- ✓ Pricing
- ✓ Well economics

Source: J. Ponce, SPE LACPEC Panel Session on Unconventional Resources (2017)

Sub Surface Factors – Complexity

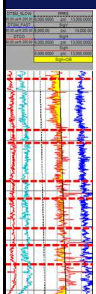


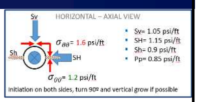
Source: Modified Vaca Muerta's Outcrop Picture, Universidad de Buenos Aires (2016)

- Important lateral and vertical variability:
  - Vaca Muerta is not the same everywhere
  - Presence of discontinuities such as carbonate "beefs", fissures and ash beds
  - Massive carbonate layers
  - De-coupled layering
- All these features threaten hydraulic fracture growth in the vertical plane, thus limiting reservoir contact

Source: Cobbold et al. (2009)

Sub Surface Factors – Geomechanics

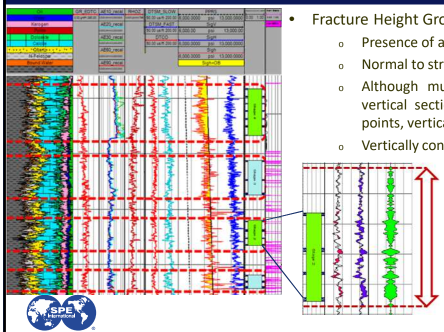




- Stress regime
  - Normal to strike-slip
    - Towards the West strike-slip dominates
    - In the Eastern region, normal regime is prevalent
    - Mixed conditions in between. It might even change within the same well
- Implications
  - Normal to strike-slip
    - In the far field away from wellbore fracture will tend to grow vertically
    - But, before growing it has to initiate along wellbore axis!
  - Normal regime: top and bottom initiation
  - Strike-slip regime: initiation on wellbore sides
    - If strong lamination, beefs, ashes, etc. are present, high probability that fracture will never turn into vertical plane!!!
- Horizontal wellbore placement
  - Where will you land the wells?

Source: J. Ponce, SPE LACPEC Panel Session on Unconventional Resources (2017)

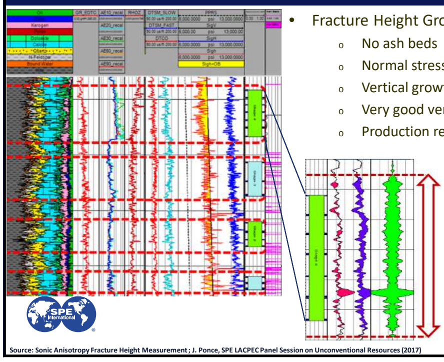
Sub Surface Factors – Geomechanics



- Fracture Height Growth Challenges:
  - Presence of ash beds
  - Normal to strike-slip regime
  - Although multiple clusters along the vertical section are used as initiation points, vertical growth is limited
  - Vertically connectivity compromised

Source: Sonic Anisotropy Fracture Height Measurement ; J. Ponce, SPE LACPEC Panel Session on Unconventional Resources (2017)

Sub Surface Factors – Geomechanics

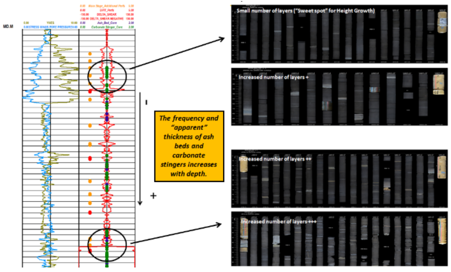


- Fracture Height Growth Challenges:
  - No ash beds
  - Normal stress regime
  - Vertical growth is not limited
  - Very good vertical connectivity
  - Production results aligned to conditions

Source: Sonic Anisotropy Fracture Height Measurement ; J. Ponce, SPE LACPEC Panel Session on Unconventional Resources (2017)

Sub Surface Factors – Geomechanics

- There is a strong correlation with the “layering” seen on core and the lost of fracture width (possible barrier to fracture height growth or disconnection points)



Source: Buijs, Ponce (SPE 189866)

Sub Surface Factors – Geomechanics

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- Casing deformation observed in multiple wells. No full collapse has been reported
  - Mainly problem has been detected while running plugs or during plugs mill-out
  - Deformations mostly in the curve section or close to perforations of fractured zone
  - More often in the harder and more laminated organic sequence
- Most likely mechanisms:
  - Localized horizontal shear at weak lithology interfaces
  - Injection induced. Thermal effects?
- With sufficient energy and fluid volumes, pressure front can propagate along weak interfaces /brittle layers inducing casing shear deformation at locations far from ongoing completion
  - Relative large fracture jobs in terms of volume
  - A geomechanically weak layer. T-shaped fractures that promote shear displacement
  - VM's special geo-mechanical conditions: anisotropy, high pore pressure, high horizontal stresses (tectonic effects), areas with strike-slip regime and ???

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Sub Surface Factors – Geomechanics

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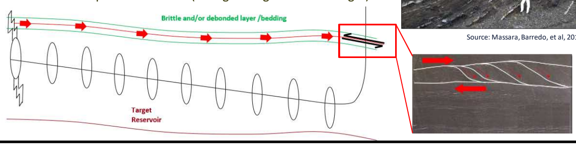
- Fine scale bedding planes (micro-laminations) in brittle layers allow for shearing to occur. Very common in organic rich mudstones and shales
  - At larger scale similar pattern as progradation's
- VM has a lot of discontinuities such as bedding, beefs, healed fractures, bed ashes
- Non-uniform loads acting on casing in the curve section due to
  - Imperfections in the cementing sheath (not easy to place good cement jobs in horizontals!)
  - Different density of natural fissures
  - Structural factors such regional curvature
  - Activation of mini-faults or planes of weaknesses
  - Potential operational issues (casing damage while running it)

Source: Massara, Barredo, et al, 2017



Sub Surface Factors – Geomechanics

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- Problem addressed but implemented solutions are still in trial phase
- Mitigation actions
  - Land curve section in zones with relative low lamination and/or minimum de-bonded bedding
  - Shut-in wells located near-by at the same level. Install a memory gauge to record pressure while fracturing neighbour wells. Apply pressure on the backside
  - Simulate pressure wave extension
  - Use a dedicated chemical tracer program to evaluate communication between wells
- Casing design
  - Use casing with higher collapse rating either thru heavier thickness or material treatment
  - If tapered string is used, run larger one deeper, so in case of deformation, plugs will still be able to pass thru. Consider slim plugs as contingency. Degradable plugs to avoid running tools in hole after fracturing
  - Further investigate actual collapse equation in curved section where casing is subjected to many different loads including non-uniform ones, bending, torsion, tension or compression, etc.
  - FEA to enhance casing design considering cementing conditions

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Sub Surface Factors – Permeability

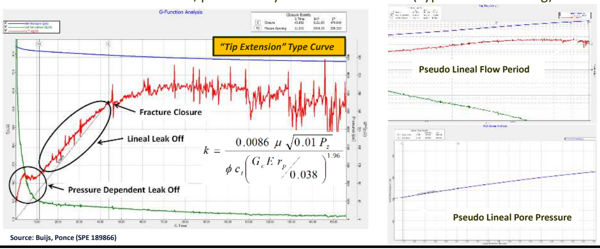
Webinars

- The G-Function: A Robust Reservoir Characterization Tool

$\Delta t_D = (t - t_p)/t_p ; G \approx 2\sqrt{\Delta t_D}$

Source: Nolte, G Function (1979)

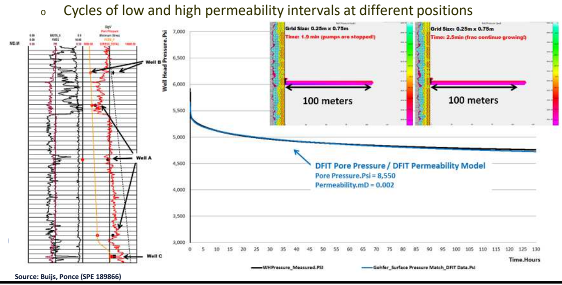
  - G-Function is a dimensionless function of shut-in time normalized to pumping time
  - This function is used to reduce ambiguity and provide important information about leak off mechanism, permeability and minimum stress (Type Curve Matching)



Sub Surface Factors – Permeability

Webinars

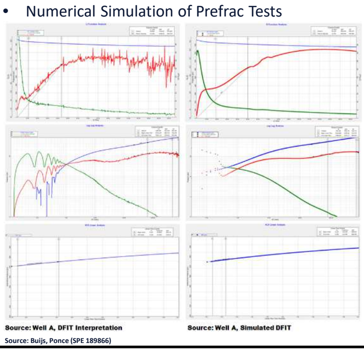
- Numerical Simulation of Prefrac Tests
  - Interval with extremely low permeability. Fracture continues growing after pumps are stopped
  - Cycles of low and high permeability intervals at different positions



Sub Surface Factors – Permeability

Webinars

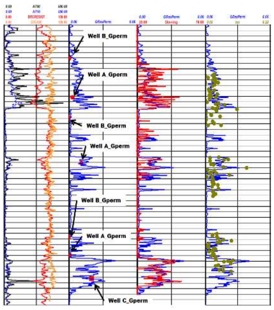
- Numerical Simulation of Prefrac Tests



  - Numerically simulated model provides similar G-function type curve, minimum stress, time to reach closure and after closure pressure transients (pore pressure)
  - Numerical model is capable of reproducing actual pressure response, thus drastically reducing the uncertainty range of possible solutions
  - Can this technique be utilized to differentiate meaningful vs meaningless Flow Capacity and State of Stress Models?

Sub Surface Factors – Permeability

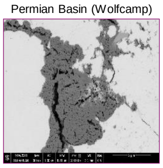
- There are high permeability channels within Vaca Muerta
  - Permeability derived from DFIT closure time are higher within higher resistivity intervals
  - When combining an independent permeability function built by integrating DFIT data from several hydraulic units with the core measured TOC:
    - Strong correlation with core measured TOC (the "slowing" curve might be used to model permeability!)
    - Correlation between permeability model and TOC, would indicate that natural fissures are related to the maturation process and sourcing of hydrocarbons



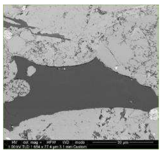
Source: Buijs, Ponce (SPE 189866)

Sub Surface Factors – Reservoir Fluids

Permian Basin (Wolfcamp)



Vaca Muerta



Source: The Challenges of Liquid Rich Unconventional Plays and their Implications on Completions and Stimulations, SPE, Ponce, 2014

- Similar maturity. Evidence that good organic porosity as seen in SEM images has positive impact on hydrocarbons storage and productivity
- Negligible organic porosity in certain areas in VM. Very low oil rates
  - Different kerogen types?, different burial history?, pores not connected?, inadequate fluid properties?
  - Not all VM has potential. Need to identify sweet spots to maximize productivity and recovery

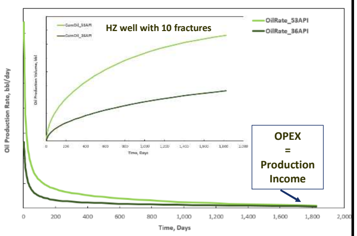
Sub Surface Factors – Reservoir Fluids

- Fluid type is mainly driven by kerogen type and level of maturity
  - Main focus on volatile oil and gas condensate
- Important properties
  - Maturity is governed by temperature and time. It depends on burial history and exhumation (it might bring fluids to two-phase envelope which is not good)
  - GOR: function of maturity
  - Viscosity: directly linked to GOR and T. High GOR and low viscosity provides high fluid expansion factor. Single phase expansion is dominant drive mechanism above bubble point pressure
  - Volume factor: a function of GOR, T and P
- All important factors converge to a highly dependence on T which is depth related
  - In VM, prospective depths below ~2,000 m where these conditions can be satisfied
- Stable phase behavior favored by high P&T
  - High pressure also critical to produce at higher drawdowns which is limited in practice by choke management practices
  - Also important to keep oil wells on natural flow for longer periods without ALS

Sub Surface Factors – Reservoir Fluids

Webinars

- Viscosity is king followed by reservoir pressure to move fluids to wellbore for the same reservoir parameters (mainly driven by permeability)
- Volatile oil window provides not only better IP but also more cumulative production over time
- Many companies put focus on EUR @ 30 years. Does it make sense?



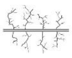
- Key drivers (P^3 rule)
  - Porosity (effective & distibution)
  - Permeability
  - Pressure

Source: Production Modelling of Multi-Fracced well; J. Ponce, SPE LACPEC Panel Session on Unconventional Resources (2017)

Technology Factors – Proppant

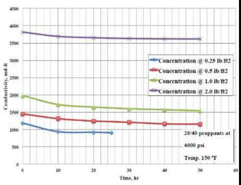
Webinars

- Main drivers for proppant selection (C^4):
  - Technical factors:
    - ✓ **C**ontact Area
    - ✓ **C**onductivity



  - Economic factors:
    - ✓ **C**ost of proppant
    - ✓ **C**apital investment strategy

  - Optimum design
    - ✓ Trade-off of technical factors driven by economics!



Source: Stimlab, 2013

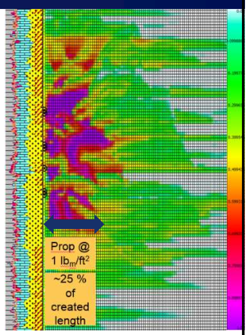
- Conductivity – the unwanted truth:
  - Base conductivity mainly a direct function of: material strength, *areal proppant concentration* and mesh size distribution
    - ✓ Actual conductivity at reservoir conditions far more lower than base conductivity. Accept the fact: conductivity gets degraded!
    - Common to observe up to 100 fold of decrease in conductivity. Run tests!

Source: SPE Hydraulic Fracturing Workshop, Neuquen. Ponce (2017)

Technology Factors – Proppant

Webinars

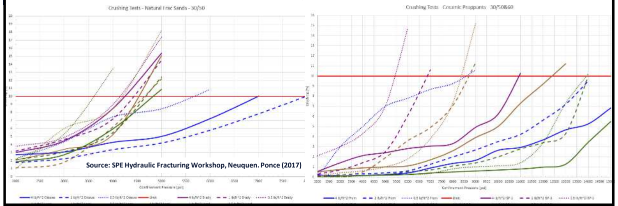
- Proppant concentration in the fracture
  - Inside the fracture defined as mass of proppant per unit of area (lb_m/ft^2)
  - VM's case
    - Even when pumping at 5/6 ppg at Surface, areal concentration in the fracture only reaches ~1 lb_m/ft^2 close to wellbore and ~0.5 lb_m/ft^2 on average
  - API/ISO proppant tests
    - Crushing: 4 lb_m/ft^2
    - Conductivity: 2 lb_m/ft^2
    - Not representative at all of conditions found in shale fractures
  - Frac width
    - NFS @ 1 lb_m/ft^2: 3.05 mm (~6 layers of 30/50)
    - ISP @ 1 lb_m/ft^2: 2.44 mm (~ 5 layers of 30/60)



Source: SPE Hydraulic Fracturing Workshop, Neuquen. Ponce (2017)

Technology Factors – Proppant

- Proppant crushing
  - Crushing tests used as proxy for conductivity behavior (both parameters are strongly linked)
    - Conductivity tests are expensive and time consuming
  - Tests done at 4, 1 and 0.5 lb_m/ft^2 to cover both API/ISO and shale frac conditions
    - Local and imported NFS
    - But selecting just based on crushing misses other important factors



Technology Factors – Proppant

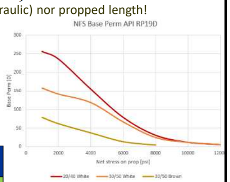
- Conductivity assessment in shale fractures. Let's go back to the basics!
  - Dimensionless conductivity (F_{CD} or C_{fD}) concept still valid for UR. If C_{fD} > 10 – 30 fracture has infinite conductivity

$$F_{CD} = \frac{\boxed{k_f * w_f}}{k * X_f}$$

  - x_f is effective propped length, neither created (hydraulic) nor propped length!
  - VM's case – NFS (pay attention to the units!)
    - k_m: 600 nD
    - w_f: 3 mm
    - k_f: base perm / 100 (degradation factor)
    - x_f: 15 m
  - C_{fD} calculations:

Net stress on prop, psi	20/40 White	30/50 White	30/50 Brown
2,000	~787	~473	~206
8,000	~103	~83	~13

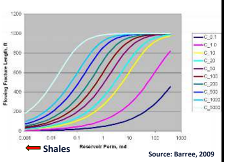
Source: SPE Hydraulic Fracturing Workshop, Neuquen. Ponce (2017)



It is fully possible to extend natural frac sand utilization beyond standard recommendations based on sound engineering practices

Technology Factors – Proppant

- Effective frac length
  - Maximum effective fracture length depends on many different factors including *reservoir permeability*, actual conductivity, clean up & drawdown management, created fracture, proppant convention and many others
  - To bear in mind: Effective << Propped << Created
  - Another hard truth: effective lengths are much smaller than we originally expect!



- Proppant convection & final proppant distribution
  - Final proppant distribution will define connected frac volume which ultimately will provide production. Critical for frac design considerations
    - Disconnected zones (even if they have the energy to move fluids to wellbore) will not contribute to frac production therefore decreasing the effectiveness of the frac potential
  - Depending on rock mechanical properties and drawdown management strategy, residual unpropped width will contribute to production for a longer period

Technology Factors – Clustering

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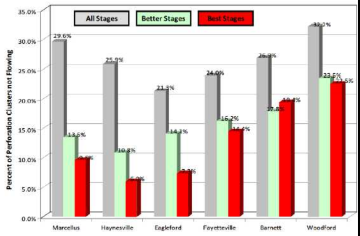
- Productivity and recovery driven by contacted reservoir
- Industry reports ~1/3 of clusters are not producing: bad reservoir and/or poor cluster design?
- Is diversion effectively achieved in P&P completions? Why not?



Source: Miller et *al*. (SPE 144326)

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Technology Factors – Cluster's Dynamics

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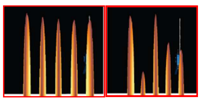
- Common assumptions:
  - Clusters are located at zones with similar rock properties (reservoir quality)
    - ✓ Brittleness index for cluster positioning
    - ✓ No stress shadowing effects
  - Evenly fluid distribution based on rate if all clusters have the same equivalent flowing area as partitioning factor
  - No difference in local velocities for fluid and proppant
  - 1D problem. Newtonian fluids
  - No pressure drop between clusters.
  - All holes are open or a couple of them does not take fluid
  - Perforations shape remains always the same.
- Are these assumptions valid? Up to what point?
- What other factors are not considered?



Plan (ideal) What we get

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Source: Cluster Dynamics ; J. Ponce, SPE LACPEC Panel Session on Unconventional Resources (2017)

Technology Factors – Cluster's Dynamics

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- Recommended approach:
  - Define an integrated workflow with G&G, RE and D&C to identify best zones (reservoir quality)
    - Move away from Brittleness Index. Use more engineered approaches based on solid physics
  - Use Navier-Stokes's equations in full taking advantage of CFD simulations
  - Understand fluid flow behavior with and without proppant. Different types of proppant to validate
  - Move to 2D and 3D solutions including non-Newtonian behavior. Frac fluids are non Newtonian!
  - Understand perforation dynamics. Use a fully coupled simulator to assess individual hole behavior
  - Perforations behave dynamically. Understand behavior along time while fracturing

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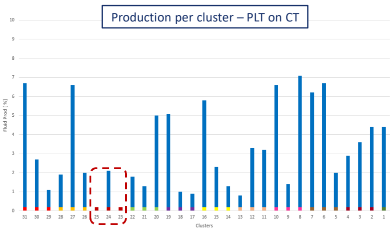
Source: Cluster Dynamics ; J. Ponce, SPE LACPEC Panel Session on Unconventional Resources (2017)

Technology Factors – Cluster's Dynamics

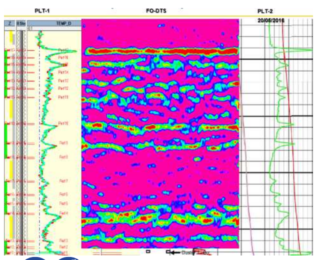


- Not too many technologies to assess production per cluster effectively.
- PLT and fiber optics (DTS&DAS) are better positioned for this task.
- Measurement of diversion effectiveness.
- Proxy for reservoir contacted area.
- Does it provide the whole answer?.

Source: Cluster Dynamics ; J. Ponce, SPE LACPEC Panel Session on Unconventional Resources (2017)

Technology Factors – Monitoring

- Validation of Modelling Results through independent measurements



"…You can not manage what you do not measure…"

- Different technologies to assess production per cluster / stage: PLT, DTS, DAS, tracers, micro-seismic:
  - Data integration
  - Synthetic PLT
  - Pros / Cons
- Understanding of production behavior along time
- Identification of sweet spots:
  - Quality
  - Benches
- Another key indicator for landing horizontal wells

Source: Cluster Dynamics ; J. Ponce, SPE LACPEC Panel Session on Unconventional Resources (2017)

Economical Factors – Benchmark

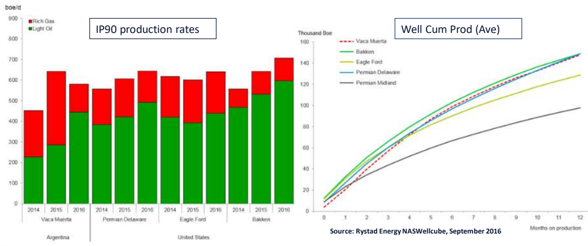
- Vaca Muerta vs Eagle Ford Shale: Production IP
  - Comparisons are not always fair but…
    - Provide a taste of actual performance when compared with well developed basins
    - Best if production is normalized but data is not always available
    - Is production per foot a good KPI?
  - Best wells in VM as of Dec 2106 produced in a range of 865 to 813 bopd as Initial Production
  - Best wells in Eagle Ford outperform VM in terms of IP
    - Choke management practices?
    - Longer wells, more frac stages?
  - Decline rate per year…valid comparison?

Oil bopd	Gas MMscfd	Well	Operator	Comp Date
5,379	5.98	1H Boothe	EOG	Dec, 2012
4,598	4.07	4H Baker	EOG	July, 2012
4,263	4.27	2H Russell	EOG	Sep, 2016
4,226	3.8	2H Bordovsky	1776 EO	Nov, 2014
3,812	5.04	2H Boothe	EOG	Dec, 2012
3,963	3.13	1H Moczygemba	Gulftex	Feb, 2015
3,664	3.09	9H Dio	EOG	Sep, 2016
3,363	2.8	1H Bordovsky	1776 EO	Apr, 2014
3,305	2.83	10H Dio	EOG	Sep, 2016
2,784	2.39	1H HB	EOG	Sep, 2015

Source: Unconventional Oil & Gas Center (Hart Energy, 2017)

Economical Factors – Benchmark

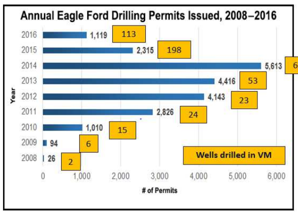
- Vaca Muerta vs Eagle Ford Shale: Cumulative Production…



Source: Rystad Energy NASWellcube, September 2016

Economical Factors – Benchmark

- Well Count
  - Eagle Ford vs Vaca Muerta
    - Normalized to time zero
  - Not all permits are drilled but as of Jan 1st 2016, 10,140 wells have been drilled in the Eagle Ford (566 wells in Vaca Muerta)
  - Drilling and Completion pace increases exponentially compared to Vaca Muerta
  - Do we have all resources in place to replicate, at least to a certain degree, what has been done so far in the Eagle Ford?
  - Is the current strategy to attract investment the right one?

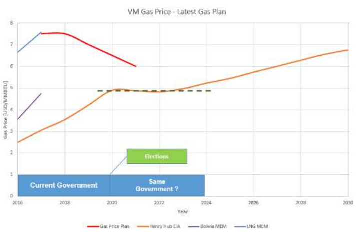


Source: Railroad Commission of Texas

Economical Factors – Investment Strategy

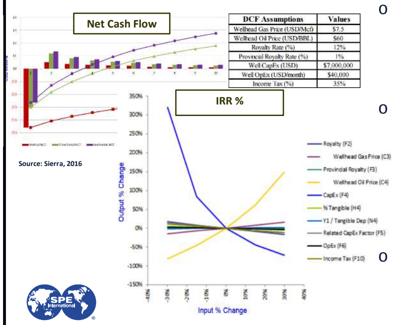
- The way the wells are produced depends on the investment strategy:
  - Need to know which one in advanced in order to design fractures properly
  - Mainly two approaches but other options are possible (I'm not blaming just saying…)
    - Aggressive production
    - Production management (commonly named "choke management")
  - Aggressive production:
    - Jump into market, ramp up production and sell asset in less than 3-5 years
    - Focus on short term economic results
    - Frac design: short spacing, natural frac sand (cheap), cheap frac fluids
  - Production management
    - Last to enter into the market, prudent development
    - Focus on medium, long term sustainable economic results
    - Frac design: engineered frac spacing based on reservoir understanding, adequate proppant selection, suitable frac fluids

Economical Factors – Pricing



- New Gas Plan for Unconventional Gas from Vaca Muerta:
  - Prices defined till 2021
  - Market pricing after that
- Can the Plan be modified if the government in place changes?
- Are Projects going to be economical at 6 USD/MMBTU?
  - What if the market prices are below 6 USD/MMBTU?
- Price abd self-sufficiency energy strategy
- "… Politics is the biggest hurdle to developing the enormous Vaca Muerta Shale…"

Economical Factors – Pricing



DCF Assumptions	Values
Wellhead Gas Price (USD/Mcf)	$7.5
Wellhead Oil Price (USD/BBL)	$60
Royalty Rate (%)	12%
Provincial Royalty Rate (%)	1%
Well CapEx (USD)	$7,000,000
Well OpEx (USD/month)	$40,000
Income Tax (%)	35%

- Base Case:
  - Public production data
  - CAPEX from public presentations
  - Current pricing
- Sensitivity Analysis and Risk:
  - Project is more vulnerable mainly to price changes and CAPEX
  - Pricing is not directly managed by operators
  - Focus on reducing CAPEX to get economical projects
- Imbibed in CAPEX
  - Labor cost
  - Labor productivity

Final Quote…

"… Finding sweet spots is like pursuing happiness, some discover it, others will eventually come up with it, some struggle in their search and some will never unearth it…"

The Experience

Acknowledgements – Questions

Webinars

- To Wintershall
  - Argentina and Head Office teams (I won't write names as I do not want to forget anybody!)
  - Special thanks to those people working in operations (in the front line!)
- To SPE for allowing me to share our journey in Vaca Muerta

Source: shareknowledgenow.nl