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VACA MUERTA – THE JOURNEY HAS JUST BEGUN

OVERVIEW, RECENT TRENDS AND CHALLENGES

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Jorge Ponce – Projects Coordinator

LEAGUE OF SPE VOLUNTEERS

CAPEX

Source: mase.lmneuquen.com, 2022

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Bio – Ing. Jorge Enrique Ponce

- ✓Currently working at CAPEX S.A. as Project Coordinator
- ✓Chemical Engineer (Universidad Nacional de la Patagonia – Arg.)
- ✓Post degree in Project Management (Universidad de Belgrano – Arg.)
- ✓+30 years of experience. Companies I worked for: Wintershall, Apache, BP, Pan American Energy, Amoco, BJ Services
- ✓Subject matter expert in well completion and stimulation in conventional and unconventional reservoirs
- ✓Local technical authority on unconventional developments
- ✓Extensive associated experience in drilling, cementing, well testing, production, reservoir engineering and integrated field development
- ✓Specialist in integrated well studies
- ✓Part time lecturer at several universities
- ✓Member of SPE and IAPG
- ✓Author of multiple publications and technical presentations
- ✓Recipient of 2013 SPE regional award – Completion & Technology Optimization
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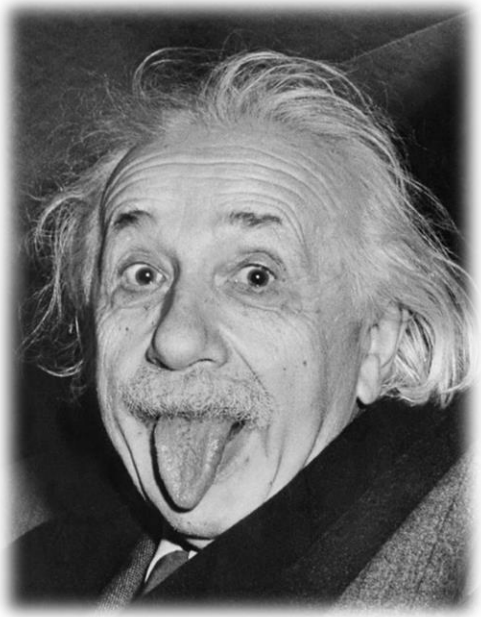
Initial Quote

"If you can't explain it simply, you don't understand it well enough".



Source: Getty Images

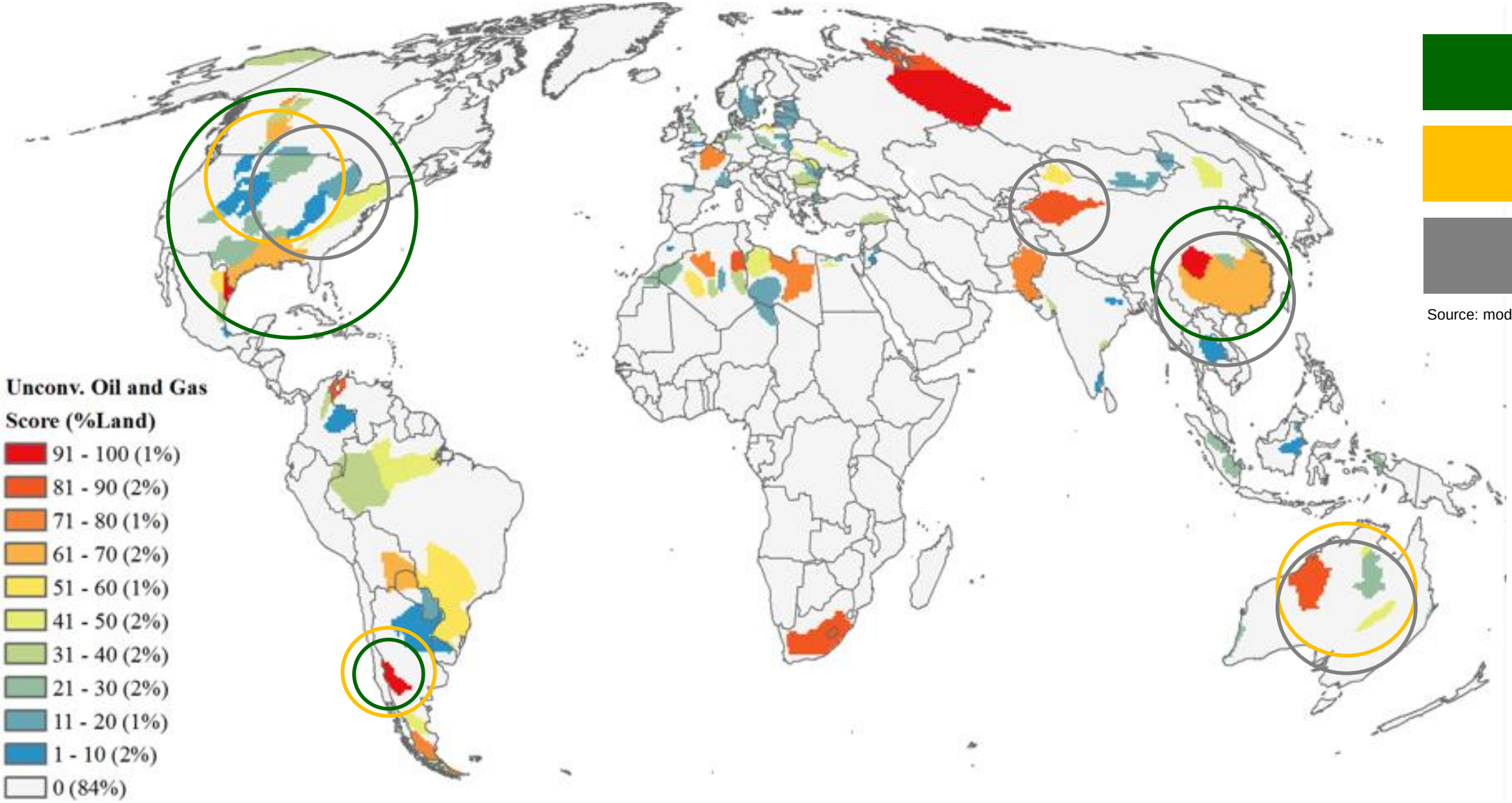
Source: Wikimedia Commons

World Geopolitical & Economical Context

- ✓ Despite the increasing proliferation of alternative energy sources (renewables), oil and gas production will continue to play an important role in the global economy. When I say alternative energy, I mean electricity
  - Hydrocarbons not only provide energy but also derivatives that no other energy source can provide
- ✓ Oil price averages at ~80 USD/bbl. No signs of rise in the short term amid Ukraine and Russia conflict. OPEC has not communicated big changes for 2023
  - Oil price mostly decoupled from conflicts in Middle East
  - COVID caused a huge impact on worldwide traveling, still recovering. Uncertainty in global economy growth
- ✓ US ranks as the country with the highest oil and gas production in the world
  - A large portion of oil production comes from tight oil and gas mostly from tight and shale gas plays
  - Resurgence of downstream industry. Cheap gas is a major reason why
  - LNG export has been increasing steadily mainly due to reduction in gas supply from Russia to Europe
- ✓ Not all companies are making money in the shale business
  - More than 200 companies have filed bankruptcy in 2020
  - In response to Wall Street concerns, companies are managing production goals and focusing on returns to investors rather than optimizing the reservoir
  - Several merges between service companies as activity picks up
- ✓ Argentina on top of world issues has its own “difficulties”. (Sorry, but I am limited in time to discuss this topic)

Source: freepngclipart.com

Unconventional Resources & Developments



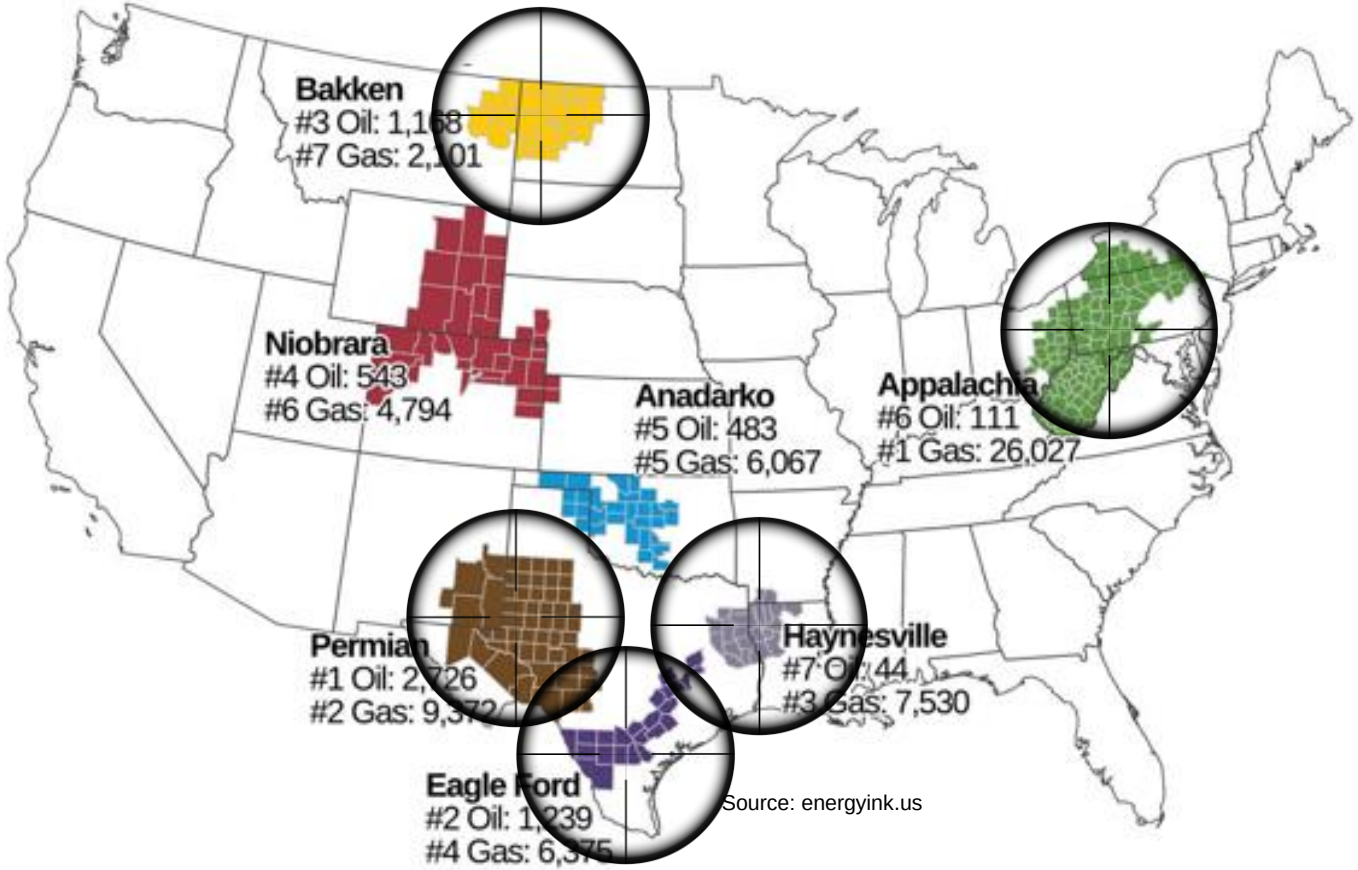
Shale

Tight

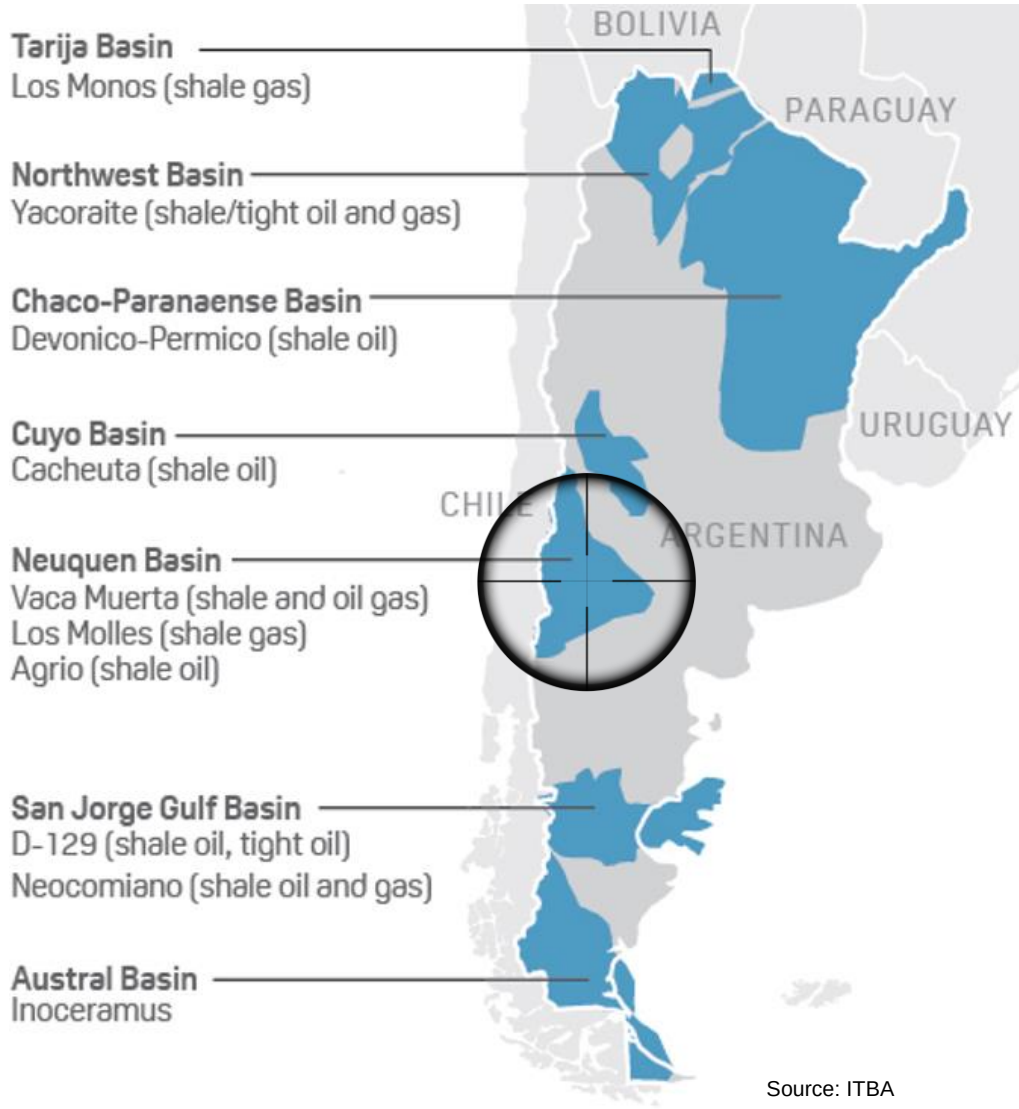
CBM

Source: modified from Oakleaf, et al., 2015

US & ARG's Most Important Shale Plays

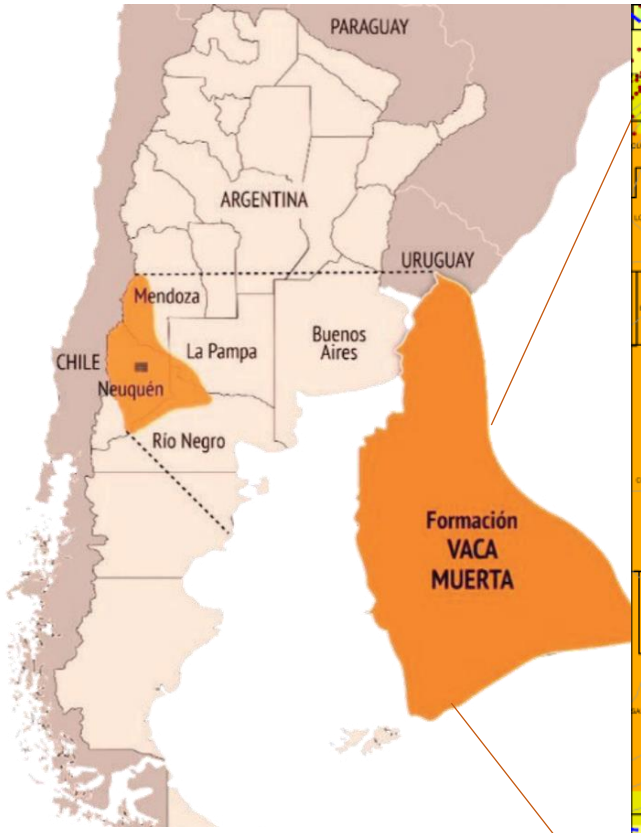


Source: energyink.us

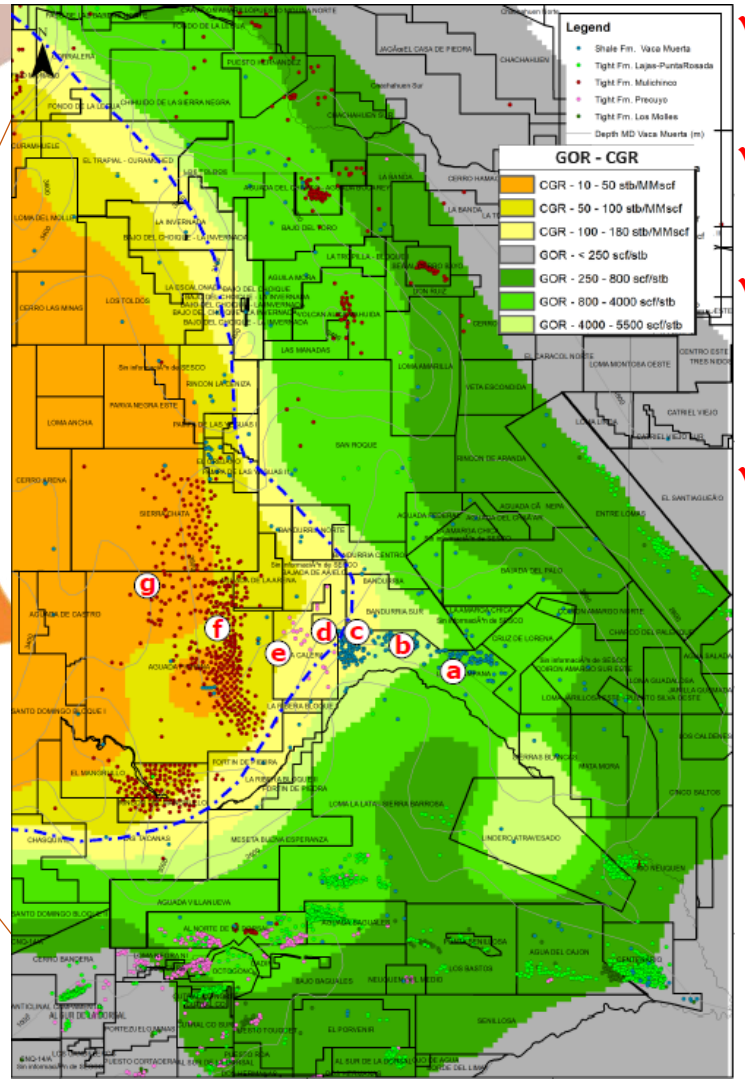


Source: ITBA

Vaca Muerta in Numbers



Source: Argentina.gob.ar

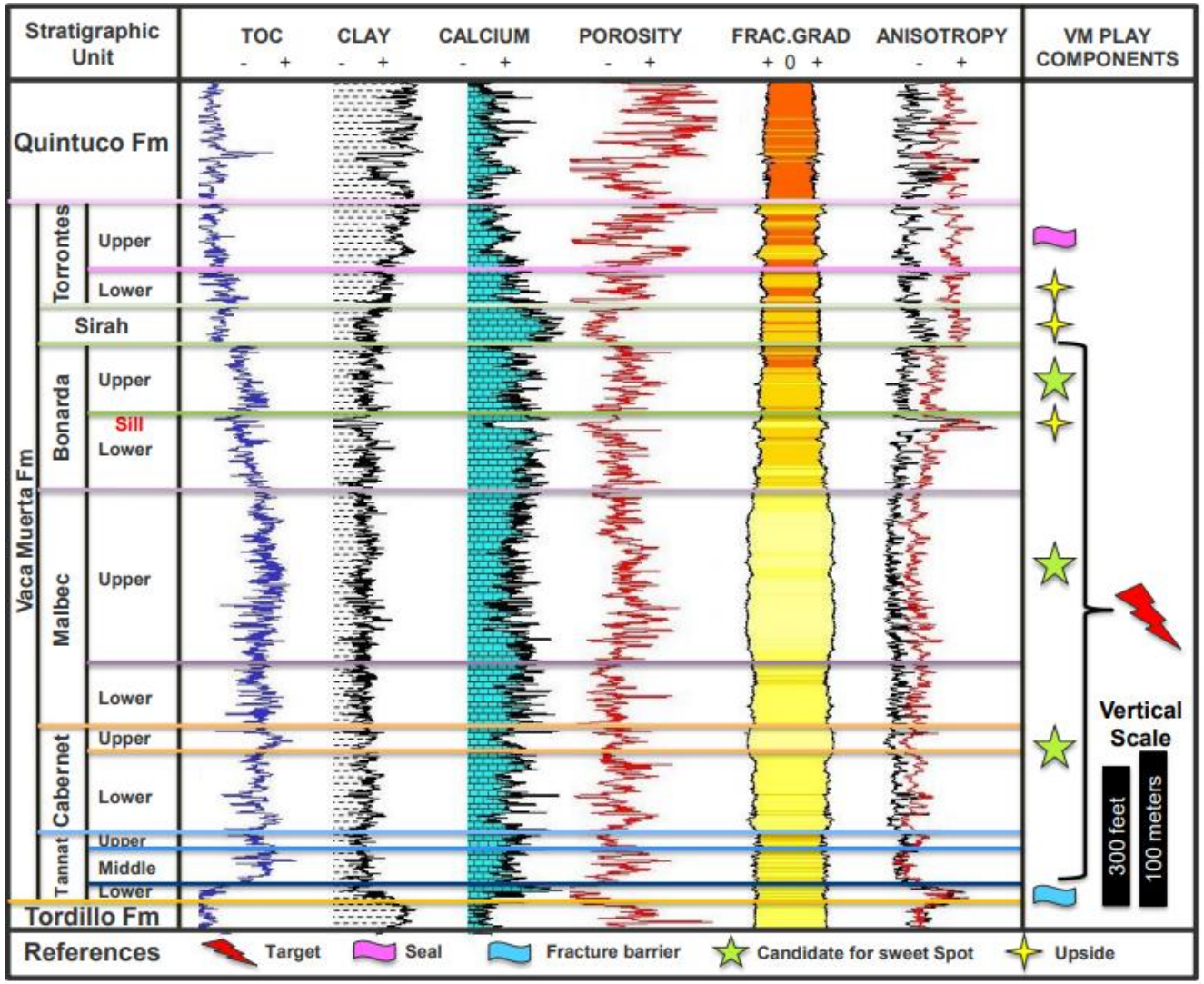


Source: Perez-Drago et al, 2018

- ✓ ~35,000 km of extension. Slightly smaller than Belgium
- ✓ Prospective acreage spans through three provinces but ~80 % in Neuquén province
- ✓ Fluid windows may change in just few kilometers. VM produces from dry gas to black oil
- ✓ Resources
  - Oil: 555,000 MMbo (4 ° in the world)
  - Gas: 2,327 Tcf (2° in the world)

Shale Play	Barnett	Marcellus	Haynesville	Woodford	Eagle ford	Vaca Muerta
Age, [MMy]	320	410	150	370	95	140
Extent, [km2]	13,000	250,000	23,000	28,900	5,000	30,000
Depth, [km]	2.0 – 2.6	1.2 – 2.6	3.2 – 4.2	1.8 – 3.4	1.2 – 4.2	2.0 – 3.5
PP Grad, [psi/ft]	0.44 – 0.5	0.4 – 0.6	0.75 – 0.94	0.4 – 0.65	0.4 – 0.8	0.6 – 1.1
Thickness, [m]	60 – 90	30 – 120	60 – 90	90 – 300	20 – 150	**30 – 550**
Porosity, [%]	4 – 5	10 – 11	8 – 9	3 – 9	4 – 15	4 – 12
Kerogen Type	II	II – III	III	II	II	II
Thermal Maturity, [Ro]	0.5 – 1.5	0.5 – 2	0.94 – 2.62	0.5 – 3	0.5 – 2.2	0.5 – 2.6
TOC, [%]	3 – 6	3 – 12	4 – 10	0.6 – 1	4.5 – 5.5	2 – 12

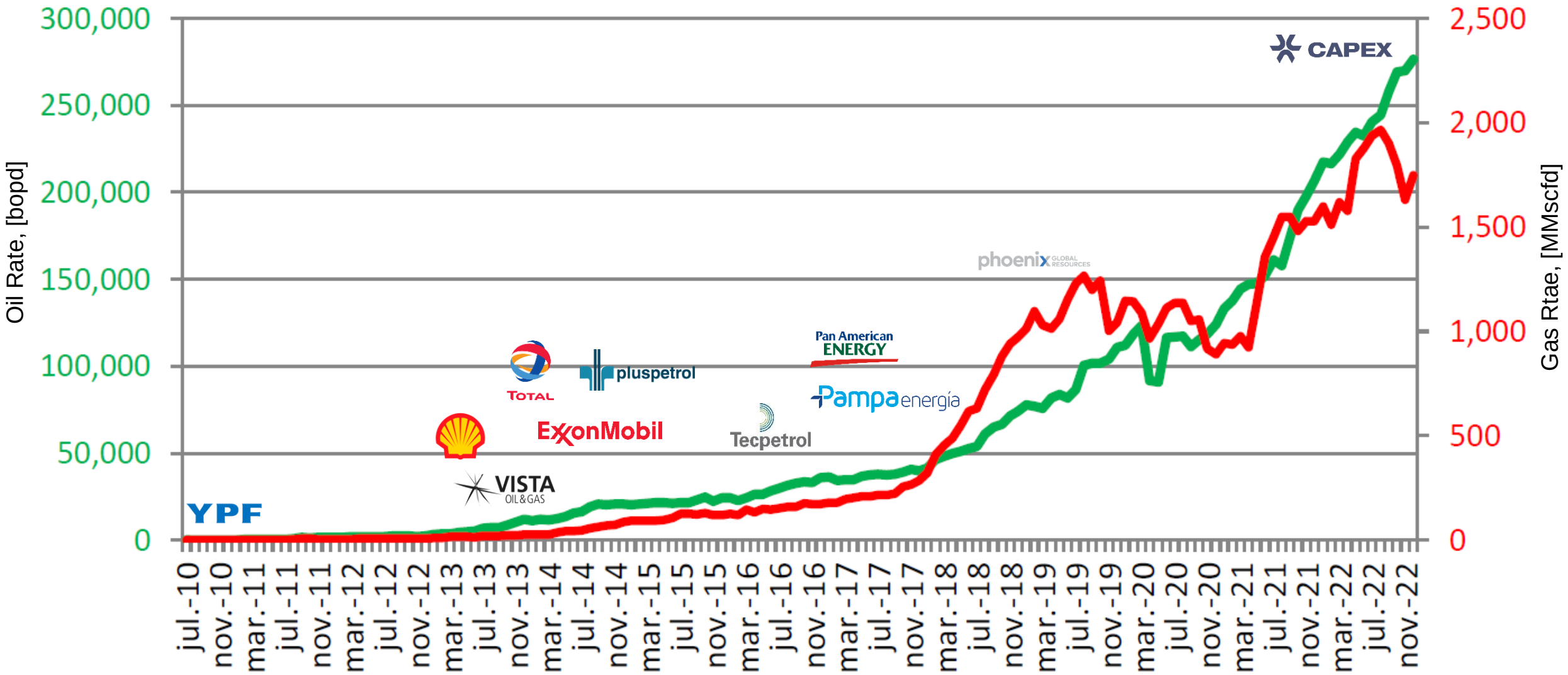
Vaca Muerta´s Landing Points



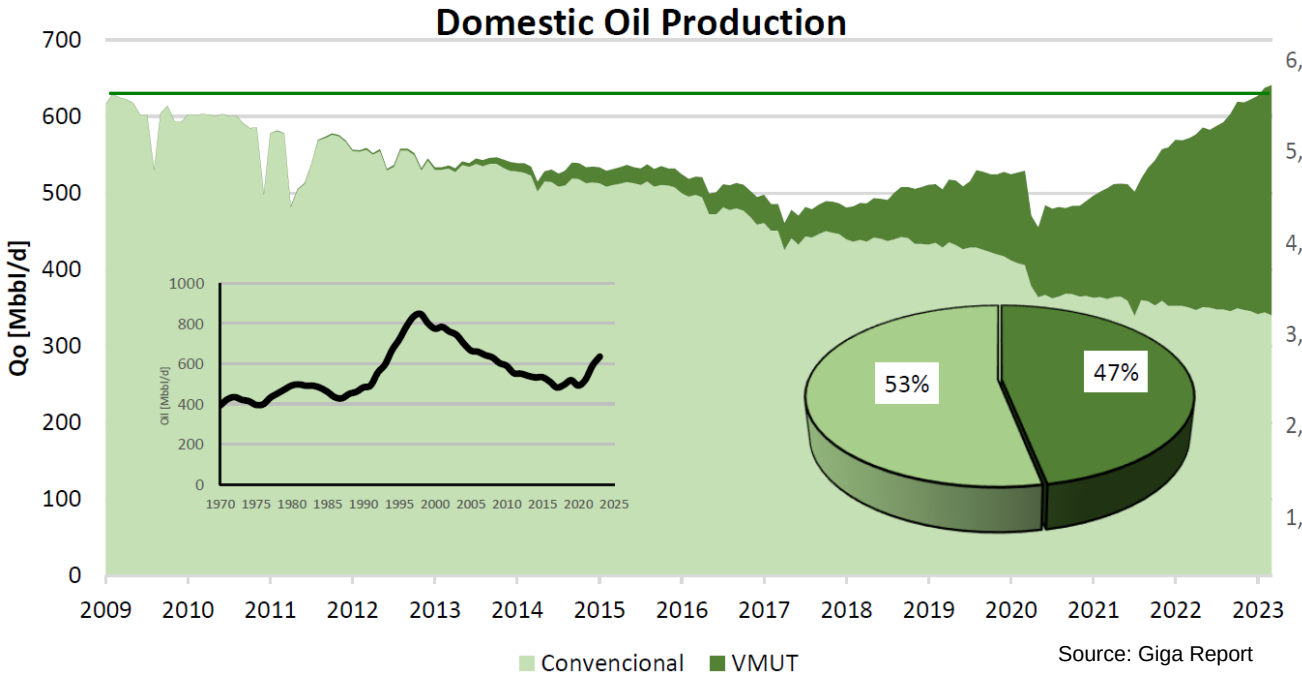
Source: URTeC 1923793

- ✓ Stacked pay potential in multiple intervals
- ✓ Lateral variations in facies
- ✓ In the center of the basin there are multiple landing points, towards borders one or two landing points depending on local position
- ✓ Current focus on “La Cocina” (hot shale section) and the organic section
  - Some companies have tested other intervals
  - Not all VM is the same, need to understand differences to focus on development in the most promising landing points
- ✓ Companies still defining optimal horizontal and vertical spacing
  - Minimization of production interference
  - Mitigation of frac hits and casing deformation issues

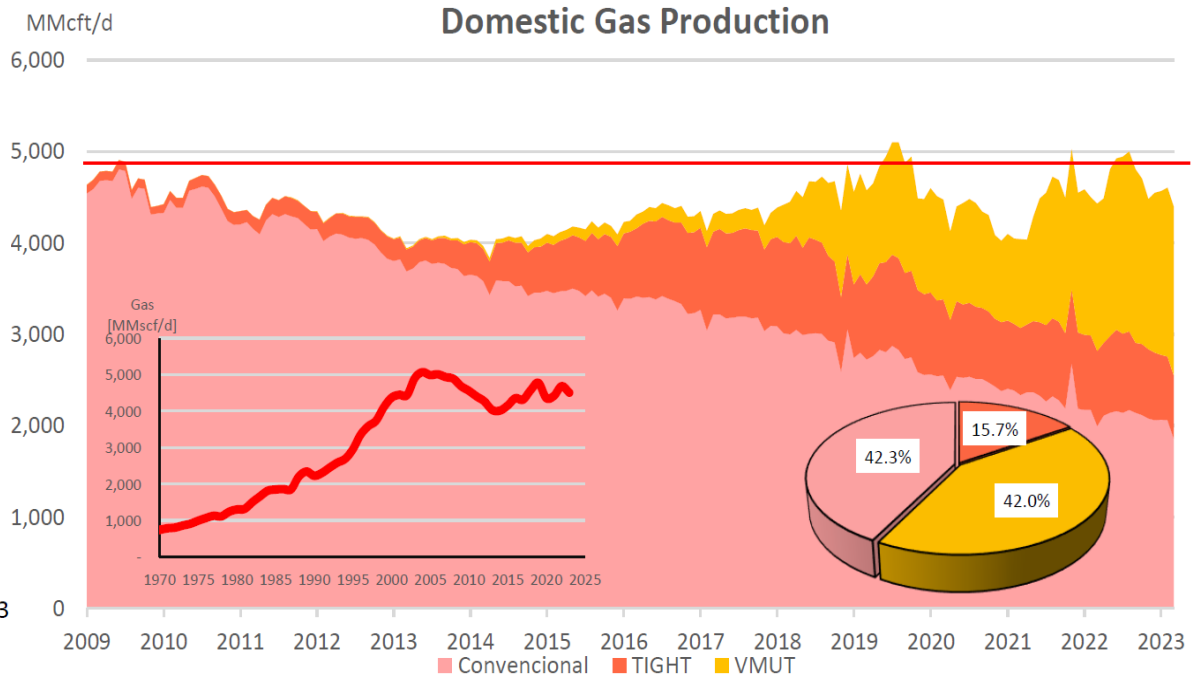
Operating Companies Activity Progression in VM



Argentina Oil & Gas Production

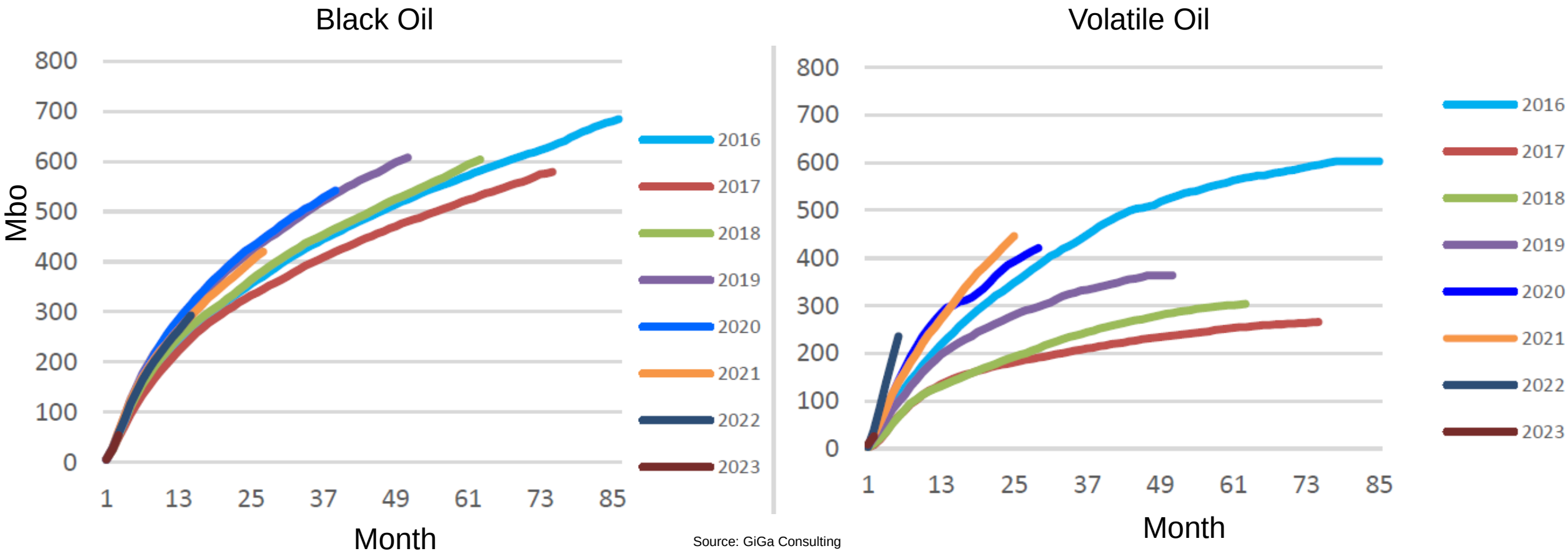


Source: Giga Report



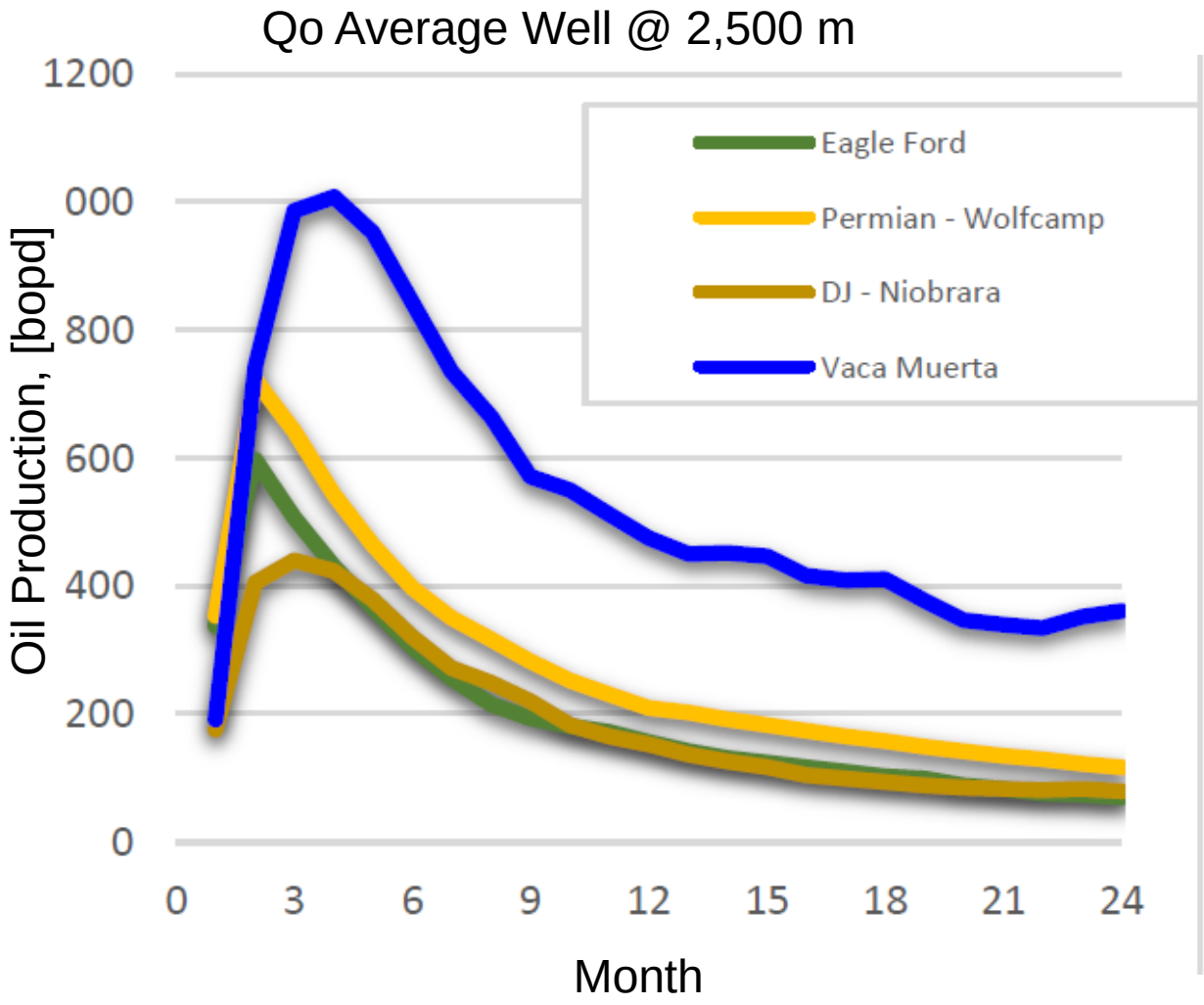
- ✓ Some facts
  - Conventional fields are declining as they are in mature phase
  - Vaca Muerta has been able to invert this trend going back to 2009´s values. Historical records already reached!
  - Argentina is the largest natural gas producer in South American region. Huge potential to produce LNG and export worldwide. Still infrastructure is a bottleneck that needs to be resolved
  - Besides Vaca Muerta there is another deeper gas shale with large resources (Molles). Actually, first multi-fractured horizontal well in Argentina was completed in Molles prior to VM

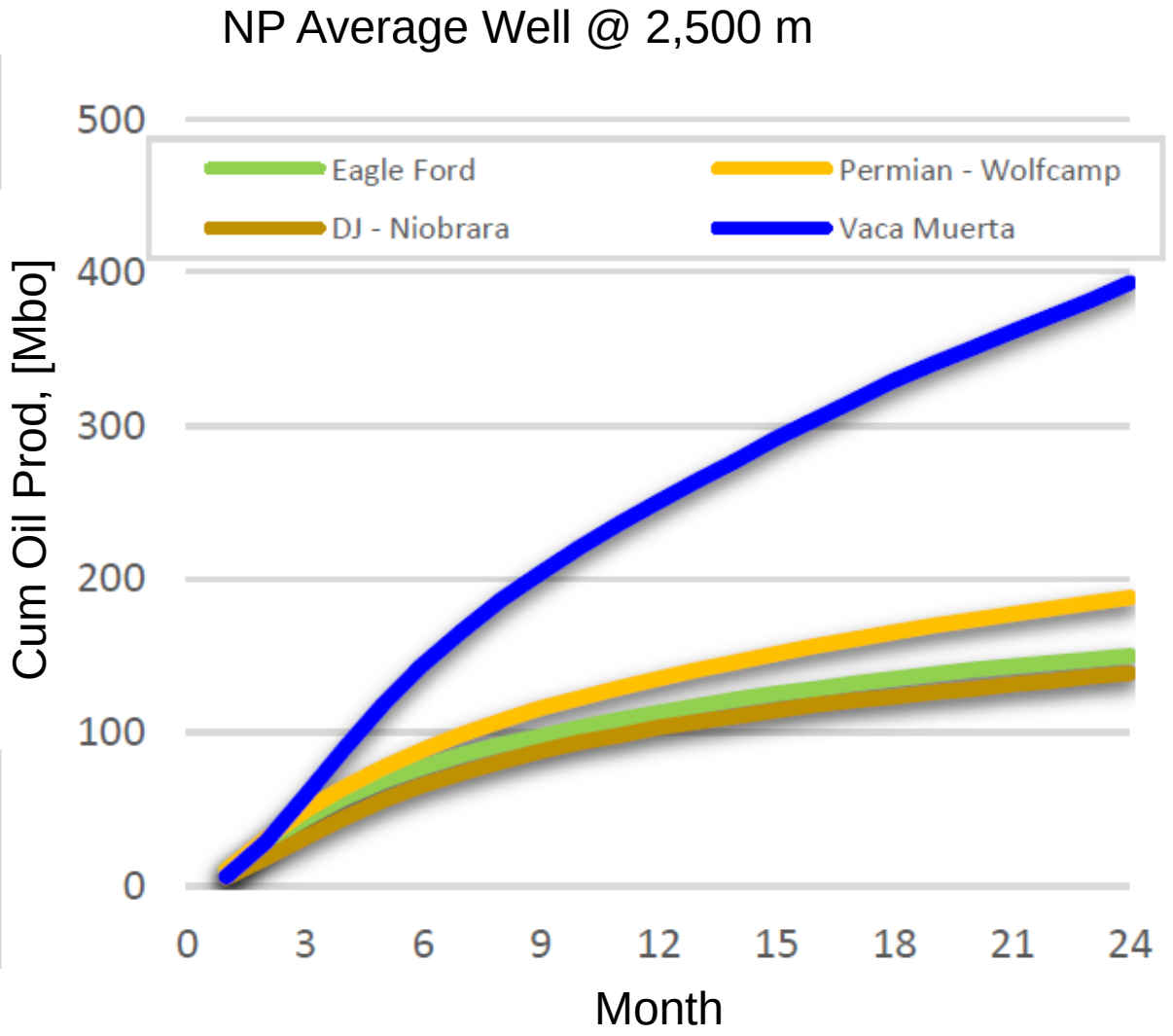
VM – Cumulative Oil Production Normalized to 2,500 m



Source: GiGa Consulting

VM vs US Shale Oil Plays Comparison

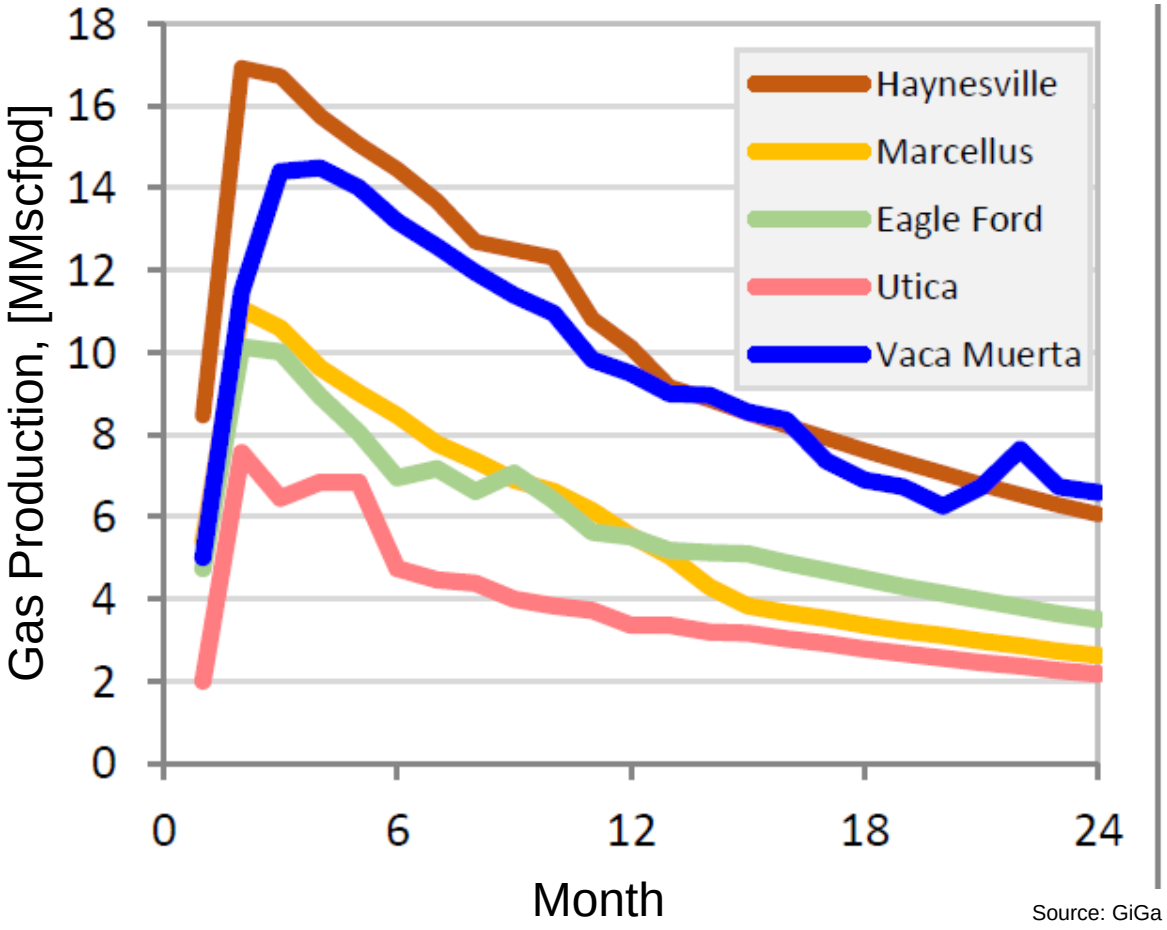




Source: GiGa Consulting

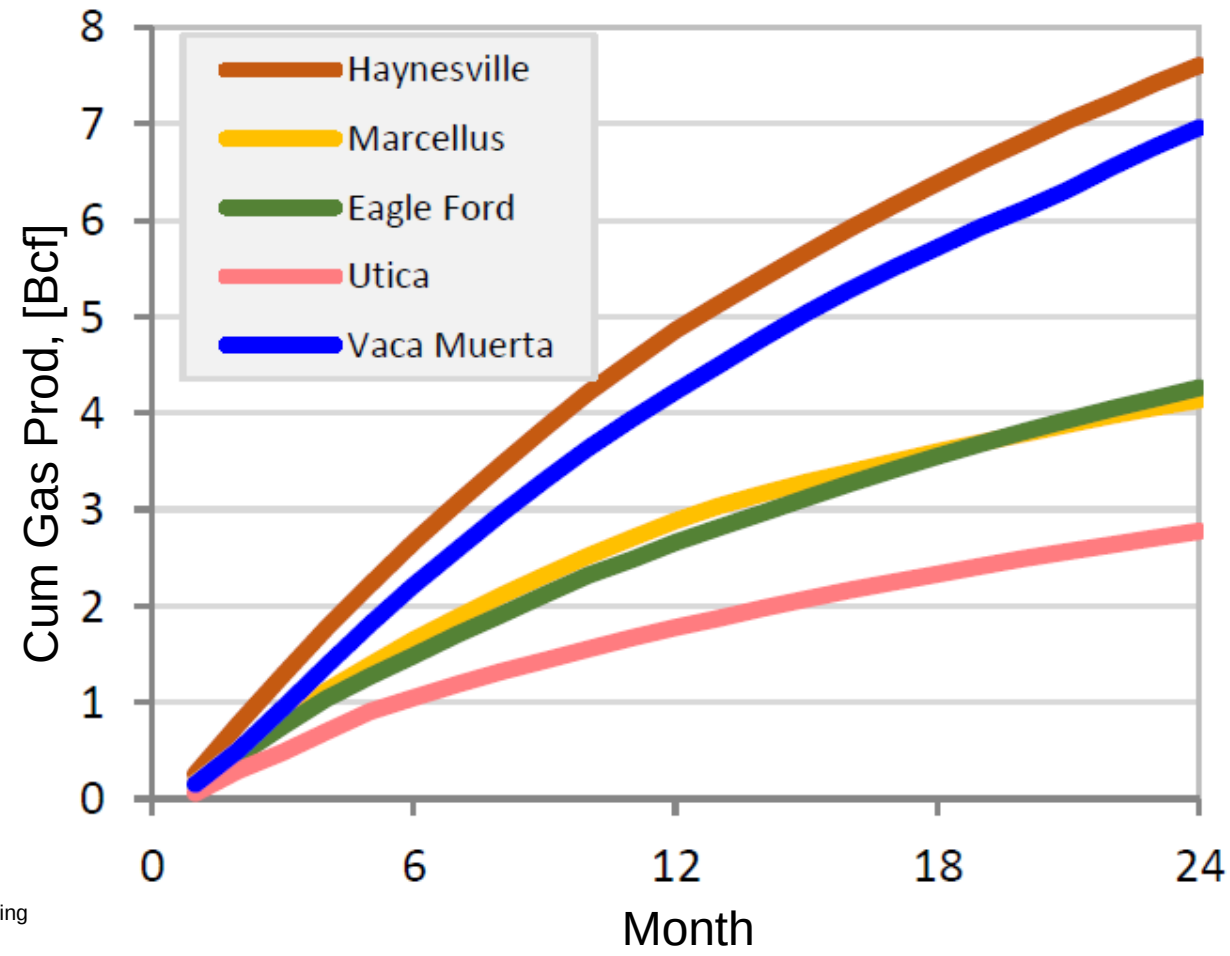
VM vs US Shale Gas Plays Comparison

Qg Average Well @ 2,500 m



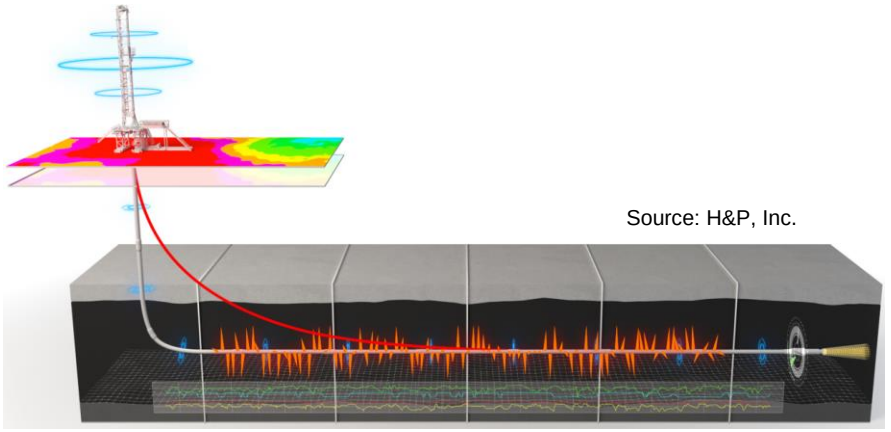
Source: GiGa Consulting

GP Average Well @ 2,500 m



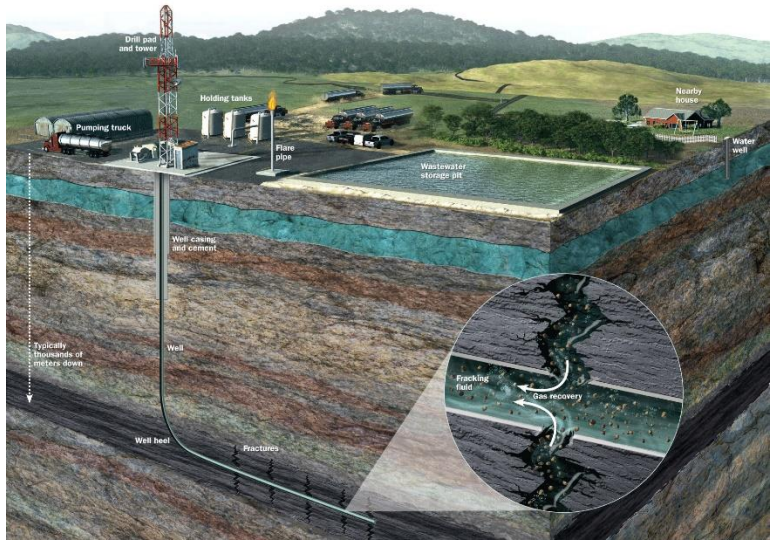
Key Technology Enablers in Shale Developments

Horizontal drilling



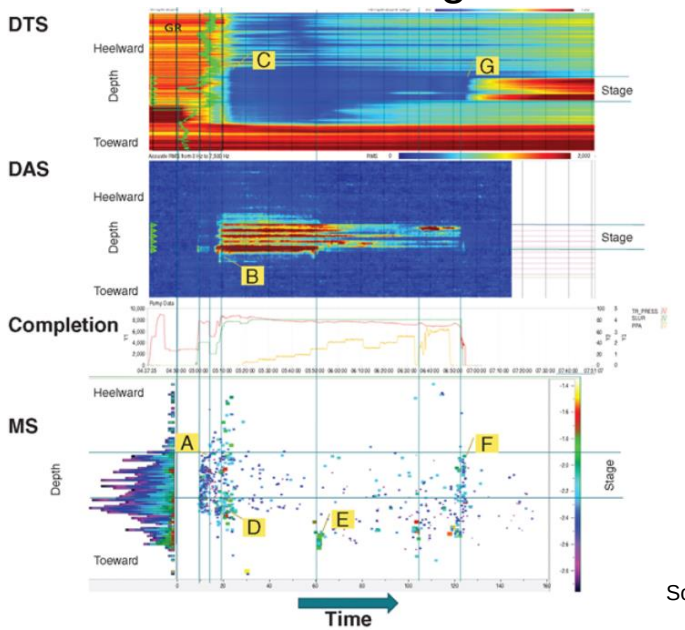
Source: H&P, Inc.

Hydraulic fracturing



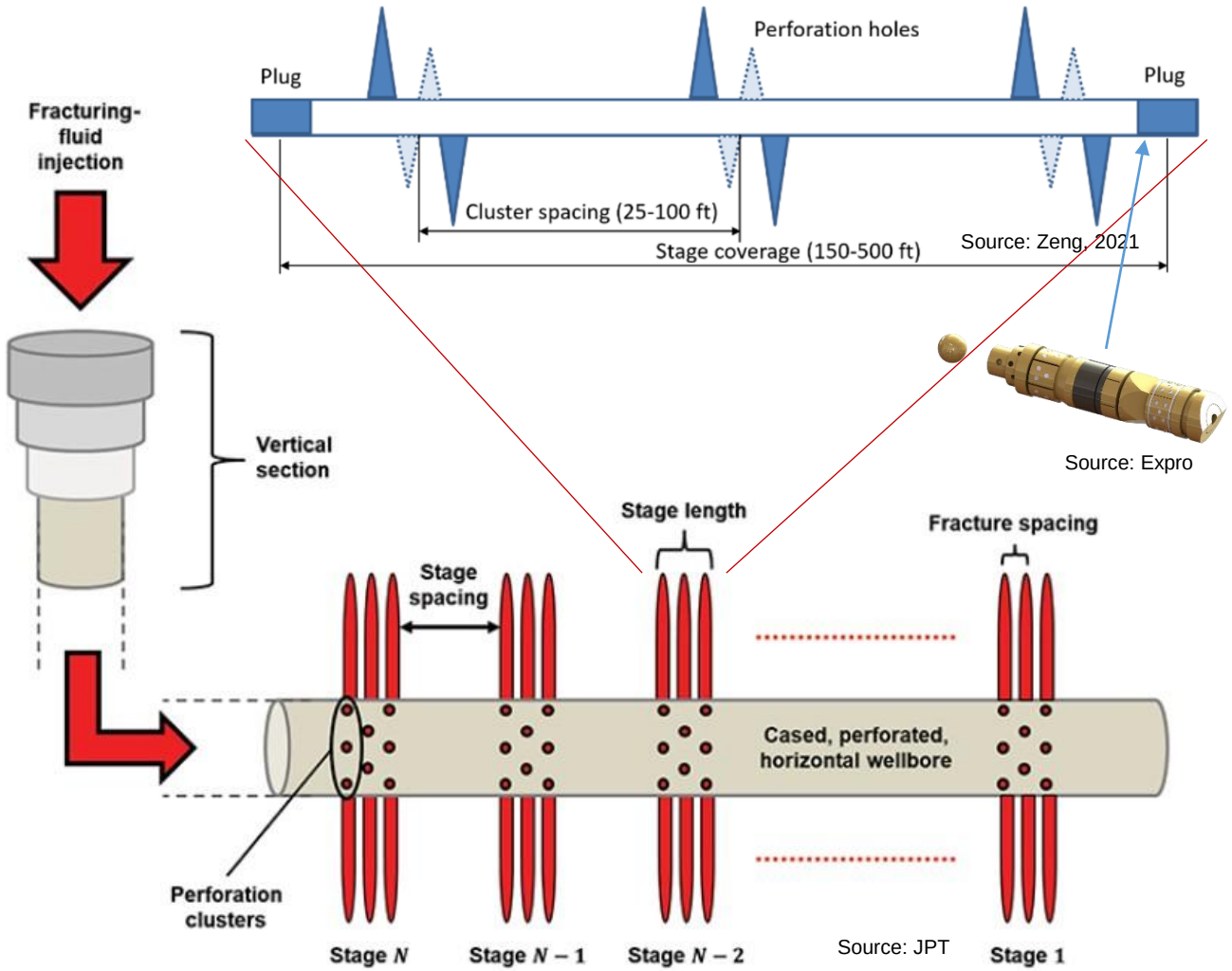
Source: Geologic Page

Monitoring



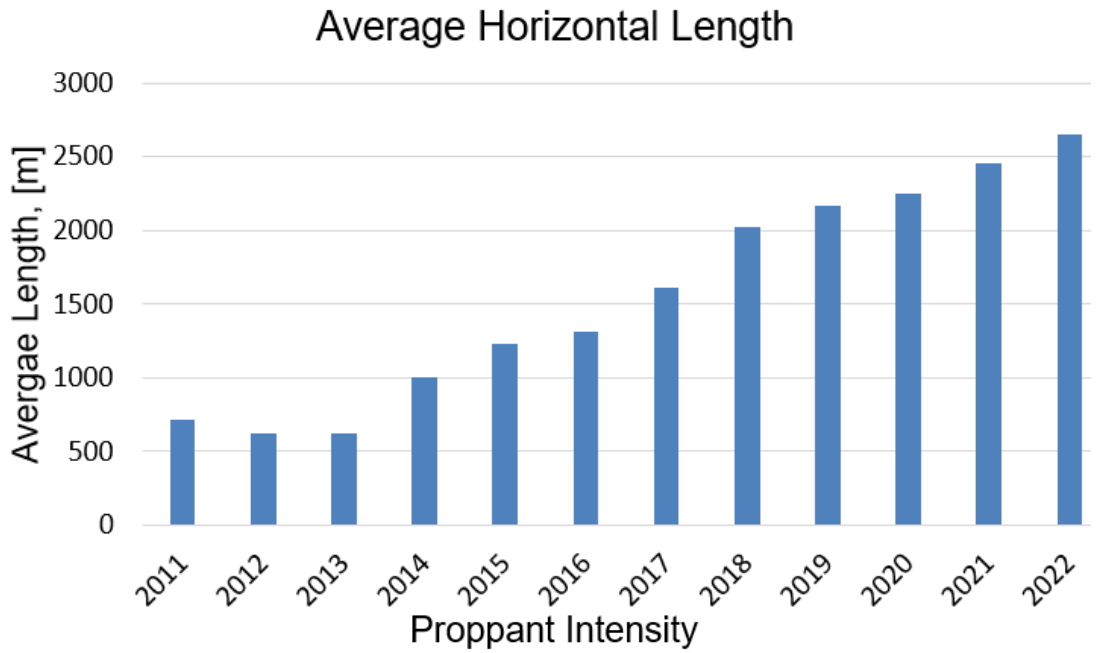
Source: AOGR, 2019

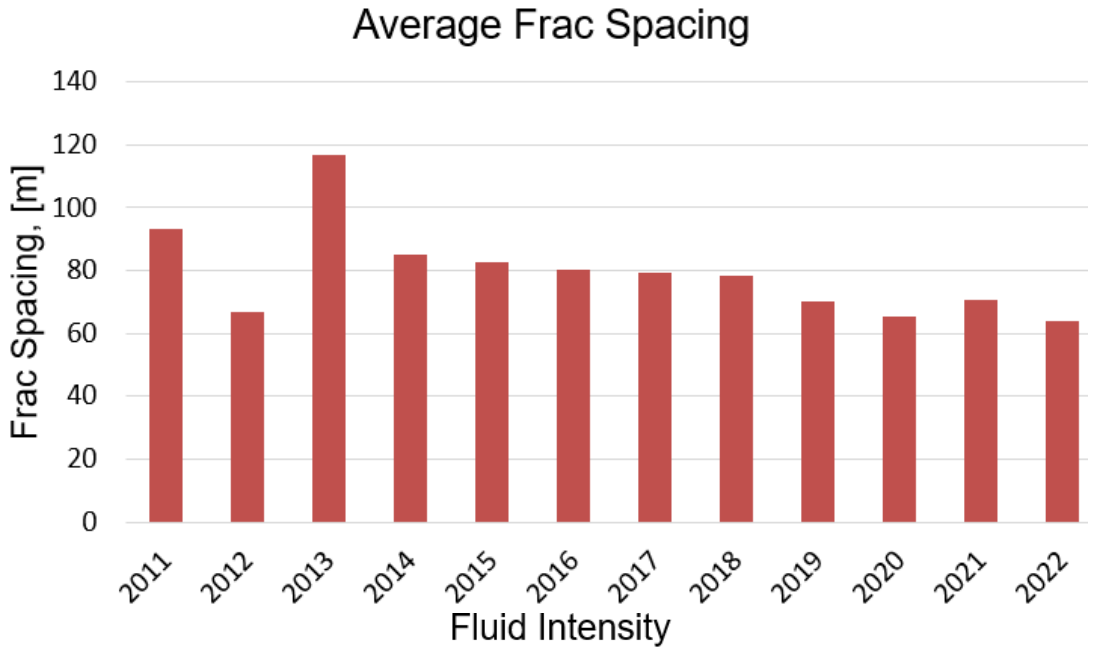
Some Basic Definitions

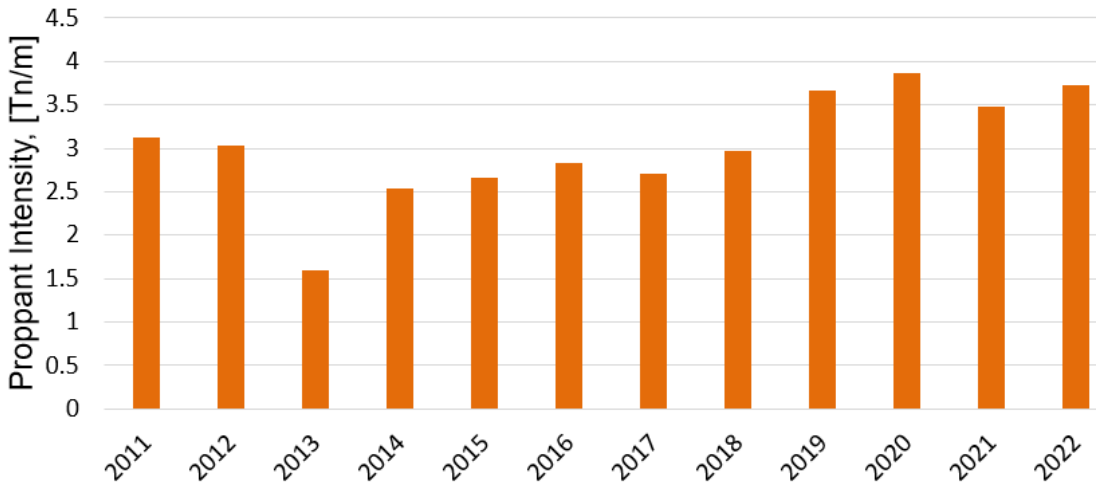


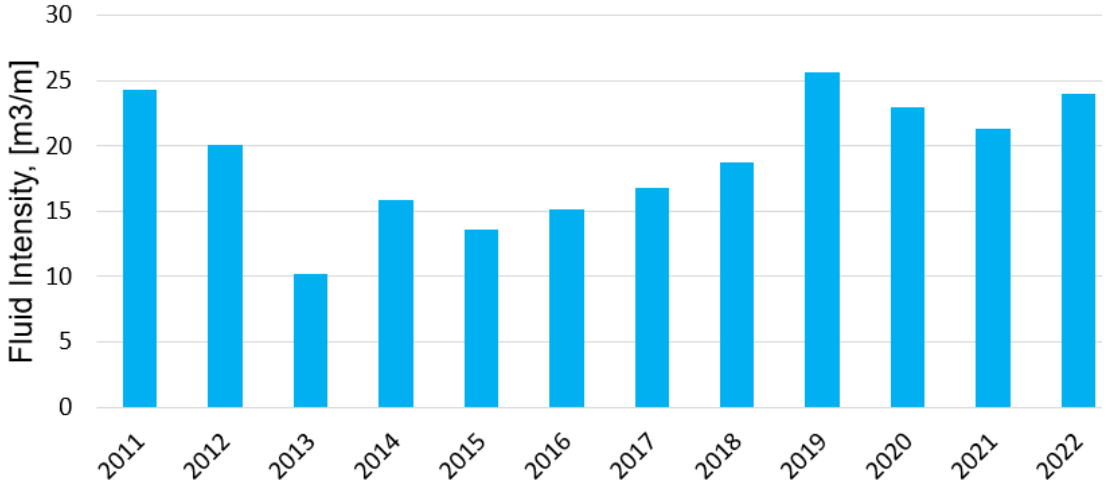
- ✓ Do not say frack, frack or fraccing. Technically and grammatically speaking, those terms do not exist. The right term is fracture, and it is abbreviated as frac
- ✓ Fracture or frac stage
  - Each individual pumping of frac fluid and proppant
- ✓ Spacing between fractures or frac stages
  - Distance between the first cluster of one stage and the last one of the subsequent one
- ✓ Clusters
  - Groups of holes perforated within the frac stage separated at even or uneven spacing with the aim of creating a productive fracture
- ✓ Spacing between clusters
  - Distance between two adjacent clusters
- ✓ Frac plug
  - Mechanical element that temporary isolate one frac stage from a subsequent one

VM Well Construction Evolution



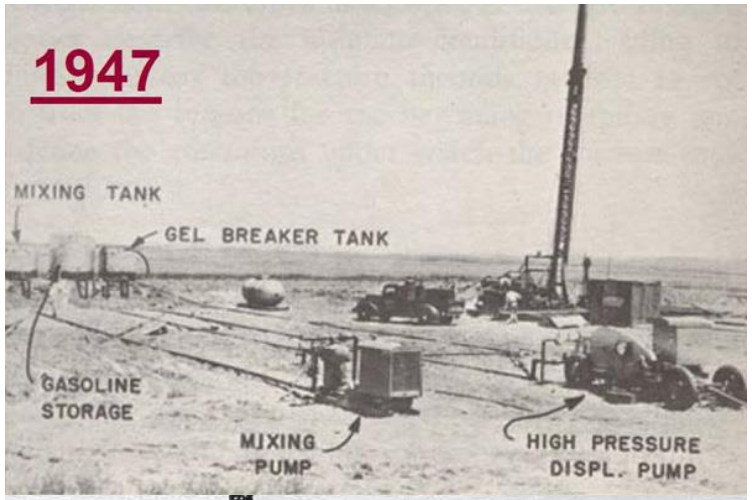


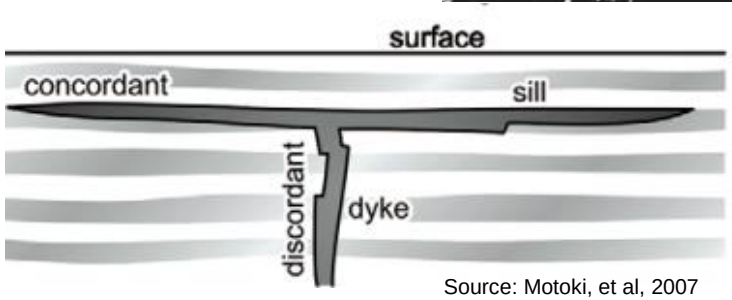


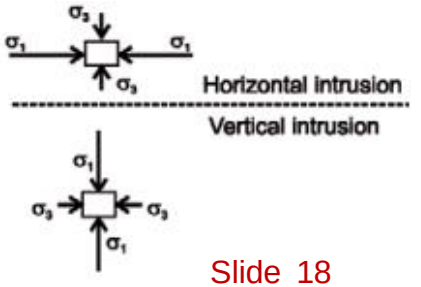


Hydraulic Fracturing – A New Technology?

- ✓ First hydraulic fracture pumped experimentally in 1947 in Hugoton field, Kansas. Stanolind, who later on became into Pan American Oil Co and Amoco Oil Co was the operator
  - Objective: mitigate damage caused by drilling in an oil reservoir
  - 1,000 gal of gelled gasoline (napalm) and natural sand from Arkansas river
  - Klepper#1 well: well produced the same after testing
- ✓ Patent granted in 1948 to Farris (HOWCO), currently Halliburton
- ✓ In May 1949 (same day), HOWCO conducted the first two commercial treatments in Oklahoma and Texas
  - Both reported as successful
  - In 1953 patent was extended to other companies and the rest is history
- ✓ First technical paper on hydraulic fracturing by J. B. Clark in 1949
- ✓ Actually, mother nature is a pioneer on hydraulic fracturing
  - Magma dykes follow the same principles being the magma the frac fluid and proppant at the same time!

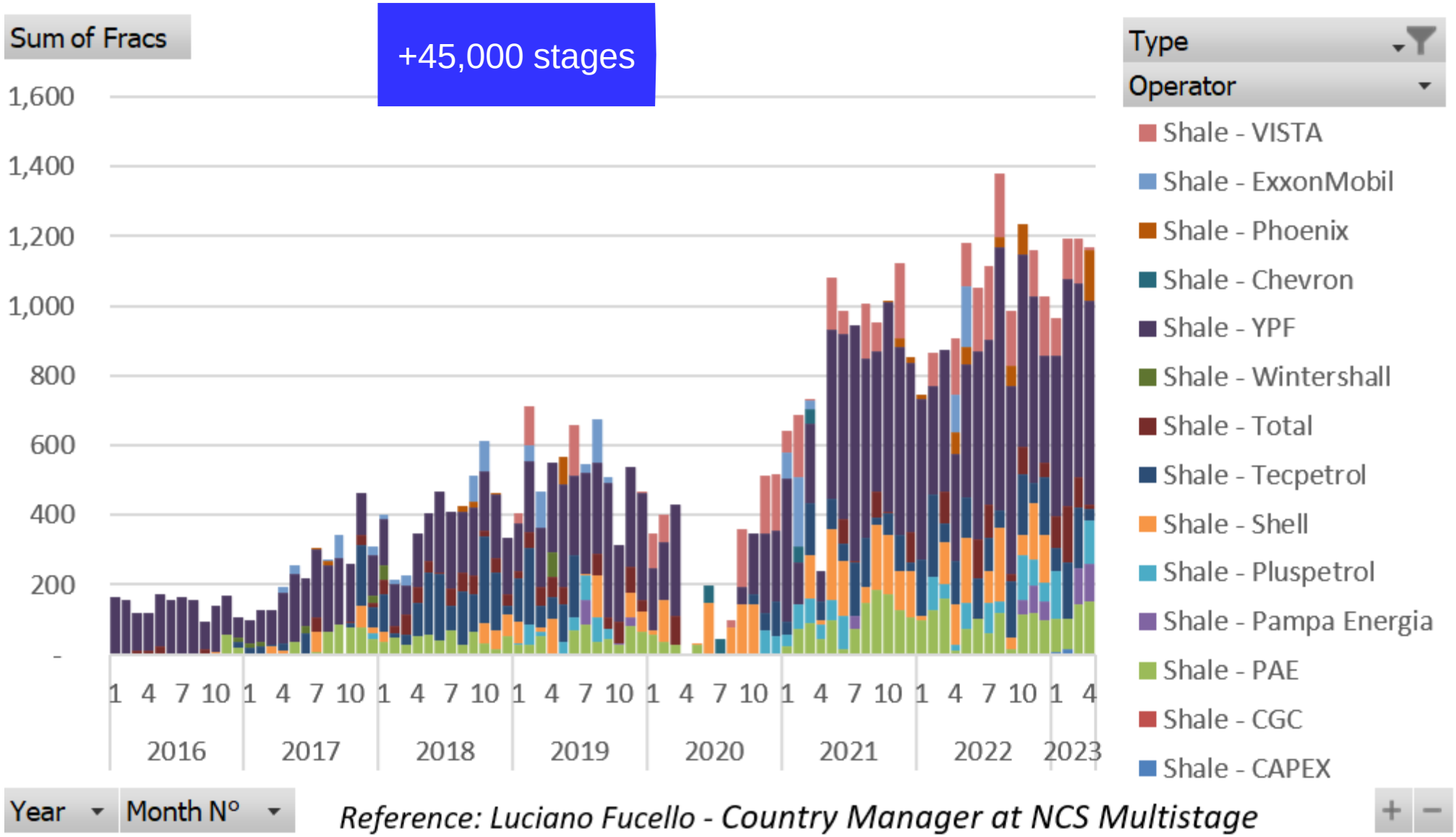






Source: Motoki, et al, 2007

ARG Vaca Muerta Shale Play – Frac Stages per Month



Reference: Luciano Fucello - Country Manager at NCS Multistage

ARG vs US's Shale Plays – Comparison at a Glance

US

- Five prolific basins concentrate mostly all unconventional production (BOE): Permian, Appalachia, Eagle Ford, Bakken and Haynesville
- Average lateral length: >3,000 m
- Stages pumped: >500,000 / yr.!
- Stages per well: 50 – 150+
- Stage spacing: 10 – 100 ft
- Cluster per stage: 5 – 25
- Spacing between clusters: 3 – 15 m
- Proppant per stage: 250,000 – 500,000 lbm
- Proppant intensity: 1,500 – 3,500 lbm/ft
- Fluid intensity: 50 – 65 bbl/ft
- Fluids: slick-water, hybrids and HVFR.

Argentina

- Only shale play in development: Vaca Muerta
- 1,818 wells drilled (71 % H) and 1,407 on production
- Lateral length: 1,500 – 4,400 m
- Stages pumped: >45,000 (since 2011)
- Stages per well: 25 – 65
- Stage spacing: 50 – 100 m
- Cluster per stage: 5 – 15
- Spacing between clusters: 5 – 20
- Proppant per stage: 450,000 – 600,000 lbm
- Proppant intensity: 1,500 – 3,500 lbm/ft
- Fluid intensity: 25 – 65 bbl/ft
- Fluids: hybrids & HVFR

ARG vs US's Shale Plays – Latest Design Evolutions

US

- Longest lateral well: 6,114 m. (Marcellus)
- Stages pumped in a well: +145. (Marcellus)
- Stage spacing: 30 m
- Cluster per stage: 15
- Spacing between clusters: 3 m
- Proppant per stage: 760,000 lbm. (Haynesville)
- Proppant intensity: 5,000 lbm/ft. (Haynesville)
- Fluid intensity: 55 bbl/ft. (Bakken)
- Proppant: 100 mesh, 200 mesh, 400 mesh, 40/70

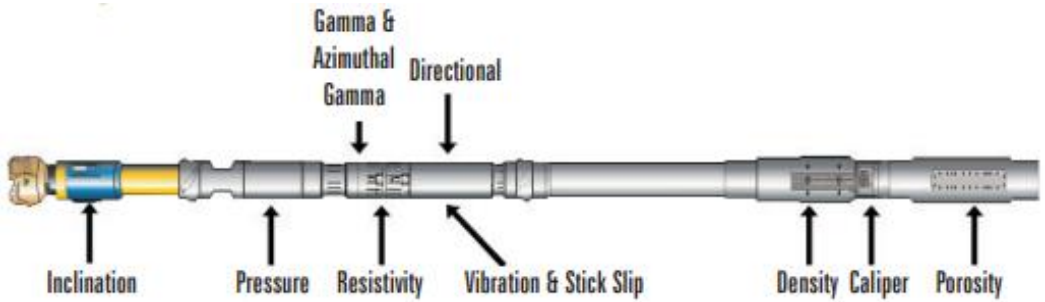
Argentina

- Longest lateral well: 4,477 m
- Stages pumped in a well: +70
- Stage spacing: 50 m
- Cluster per stage: 10
- Spacing between clusters: 4 m
- Proppant per stage: 4,500 – 6,000 lbm
- Proppant intensity: 3,000 – 4,000 lbm/ft
- Fluid intensity: 65 bbl/ft
- Proppant: 100 mesh, 40/70, 30/70

Technology Enablers – Geosteering

Source: Roggi, 2020

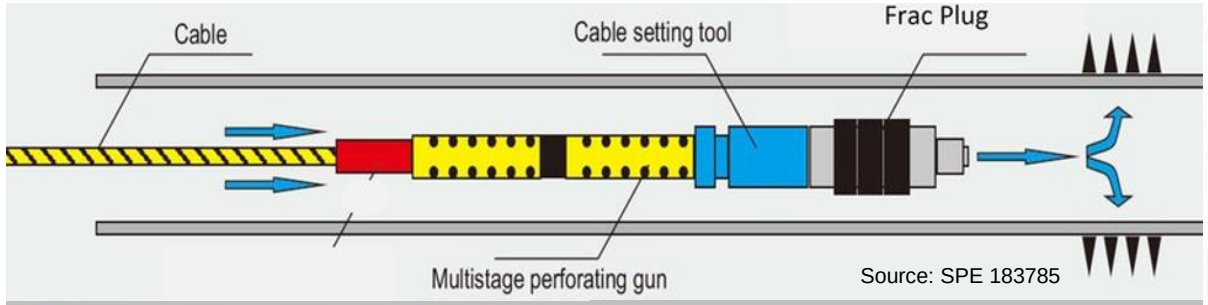
Source: SLB, 2022

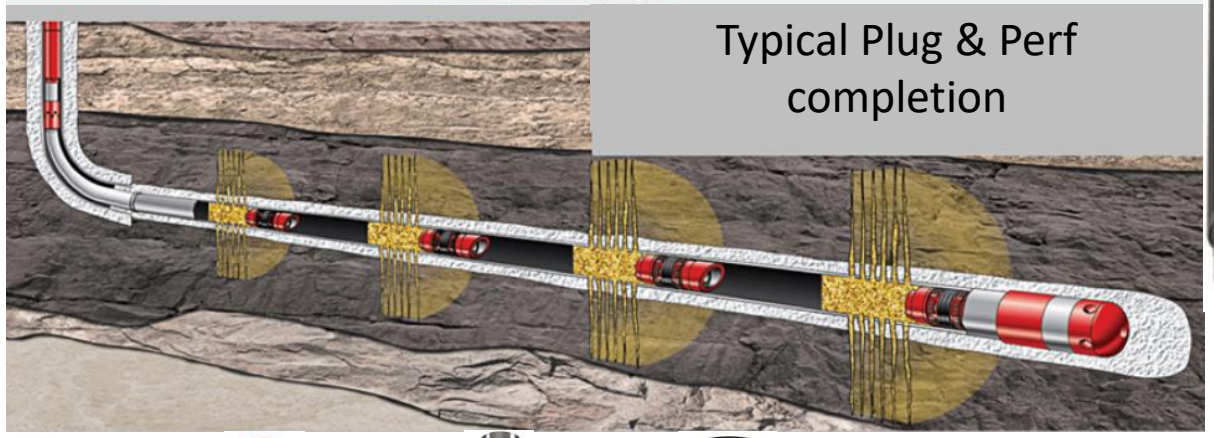


Source: Drilling Contractor, 2003

- ✓ Geology
  - At seismic scale, in many cases, it looks relatively simple but at real scale is complex
  - Navigation windows are in general narrow (<10 m)
  - It is not uncommon to cross thru faults not noticed in the seismic
- ✓ RSS
  - Latest technologies have allowed reducing drilling time, tortuosity and overall drilling cost
  - Near-the-bit steering proves very useful
- ✓ MWD/LWD
  - MWD used for positioning
  - GR is the standard tool but in specific wells full suite is run

Technology Enablers – Plug & Perf Methodology





Source: Repstim, 2021


Source: SLB


Source: WTF

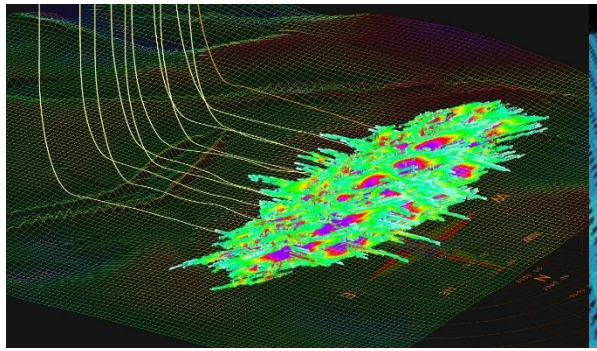

Source: HES


Source: WTF

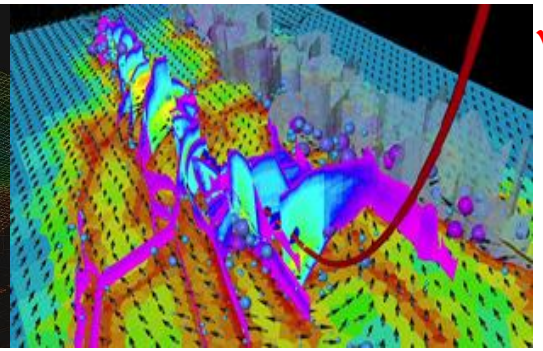

Source: SLB

- ✓ Basics
  - Method allows setting a plug and perforating multiples zones “clusters” in a single-run on wireline pumping down in the horizontal section
  - Technology derived from conventional plug setting and casing perforation on wireline. Everybody knows it!
- ✓ Technology evolution
  - Addressable switches allows firing more than 25 guns if required plus setting the plug
  - Quick perforating modules to reduce preparation time and increase efficiency
  - New charges with consistent entry holes
  - Continuous improvement in frac design from aluminum to degradable materials and from bulky to small-volume plugs
  - Streamline cable to reduce friction, enhance reliability and to eliminate grease to pack-off

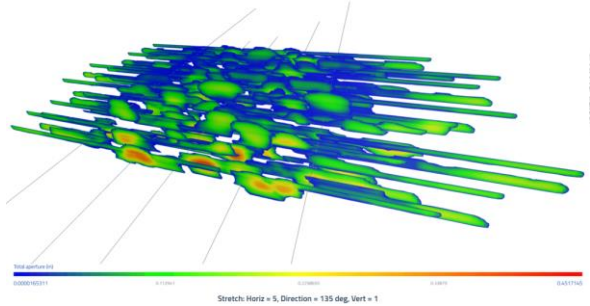
Technology Enablers – Frac Simulators



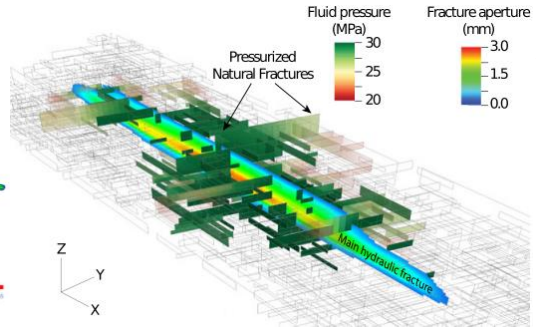
Source: GOHFER, Halliburton



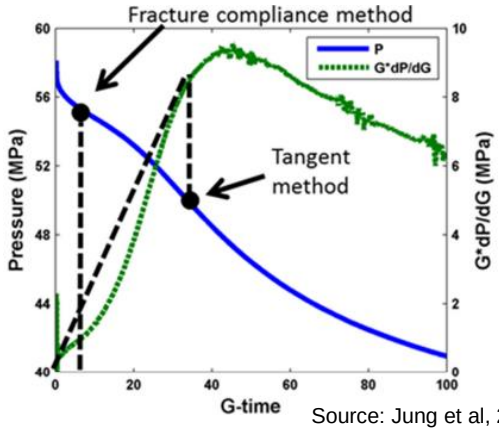
Source: Kinetic, Schlumberger



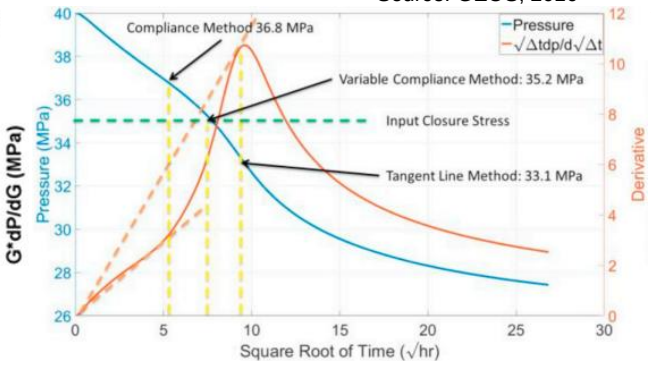
Source: Resfrac



Source: GEOS, 2016



Source: Jung et al, 2016



Source: Wang et al, 2020

- ✓ Challenges
  - Hydraulic fracturing in horizontal wells is an extremely complex process as there are many interrelated variables. We do not know the whole physics!
  - Even if we are fracturing, we need to integrate at least geology, drilling, geomechanics, rock mechanics, reservoir and production engineering, fluids engineering, well testing, etc.
- ✓ Available solutions
  - Several tools available in the industry that partly respond to current challenges
  - Most of the time we do not have the information to feed in the simulators! Garbage in, garbage out!
- ✓ Evolution and limitations
  - Current focus on understanding clusters physics
  - Logs do not have enough resolution to capture shale laminations
  - Still debate among simulating tools developers about some basic parameters such as closure pressure and how to obtain it

Technology Enablers – Frac Fleets

Source: rionegro.com.ar

Source: JPT, 2020

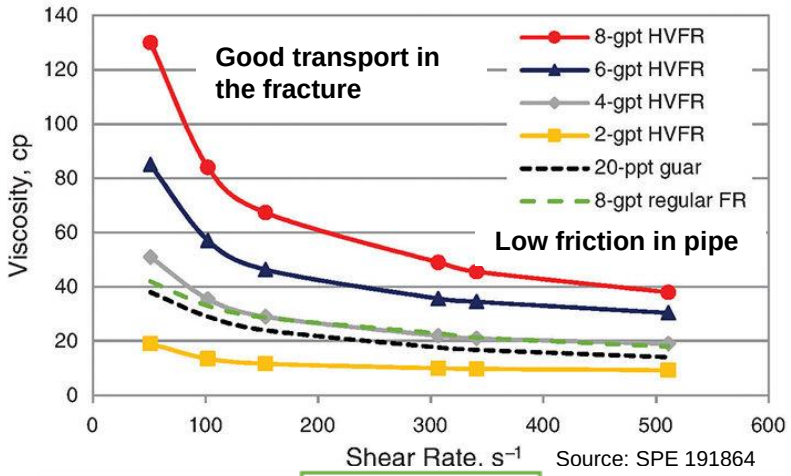
- ✓ Where do we come from?
  - Conventional frac fleets designed to pump relatively small to medium-size treatments for a short period. Easy maintenance or equipment replacement
  - Low treatment pumping rates and moderate wellhead pressures
  - 1,000 – 2,000 HHP pumps
  - Low footprint. Fueled by gasoil
  - Proppant, water and fuel logistics are not an issue
- ✓ New requirements (efficiency is paramount!)
  - New pumps with higher HHP per unit and higher output pressure. Ability to pump 24-7 if required
  - More efficient engines. Low maintenance. Low noise and emissions
  - Less iron. Focus on pumping rather on rigging up or testing lines
- ✓ Evolution (the future for Vaca Muerta)
  - 3,000 – 5,000 HHP pumps with new fluid ends for extended pumping time. Lower footprint as fewer pumps are required
  - Introduction of electric fleets powered by natural gas. More efficient, less noise and emissions. More expensive as well!
  - Monobore missiles to reduce rig-up time and minimize leaks

Technology Enablers – Proppants & Related Issues

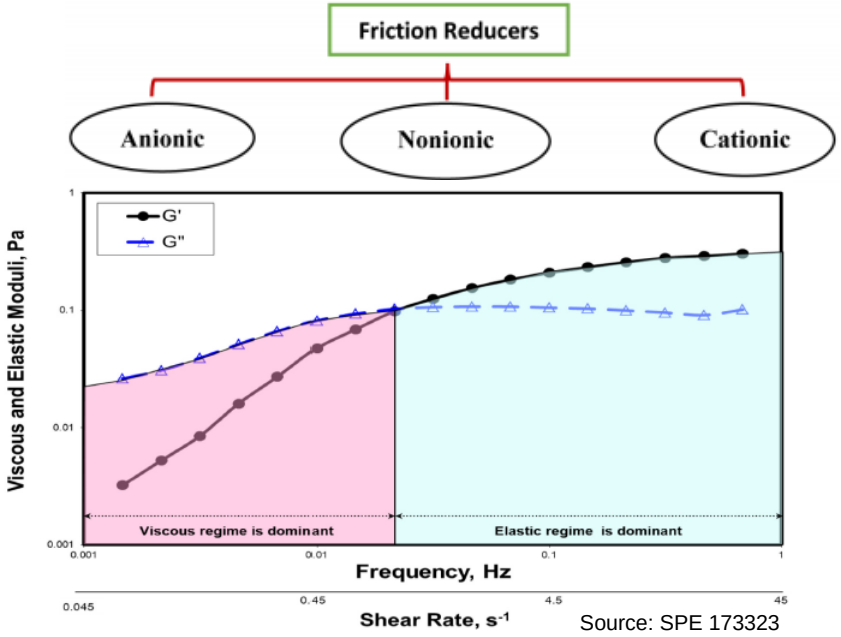
Source: bariteworld.com

- ✓ Evolution
  - Initially wells fractured with ceramic proppant to take proppant strength out of the equation in productivity evaluation
  - Treatments evolved to hybrid designs comprising ceramic and natural frac sand mostly imported from US
  - Currently mostly all wells are fractured with national natural frac sand from different sources. Local sand equivalent to brown or Brady sand
  - Mesh sizes have gone from 20/40, 30/60 and 100 mesh to 30/70 and 70/140
  - Firstly, proppant was transported in big bags to location, but loading process was very slow. Currently modular solutions are the common practice
- ✓ Next steps
  - Use of wet sand (first field tests are being carried out). Reduction in manufacturing and transportation costs. Less emissions, dust and water utilization (ESG)
  - In-basin sands

Technology Enablers – Frac Fluids



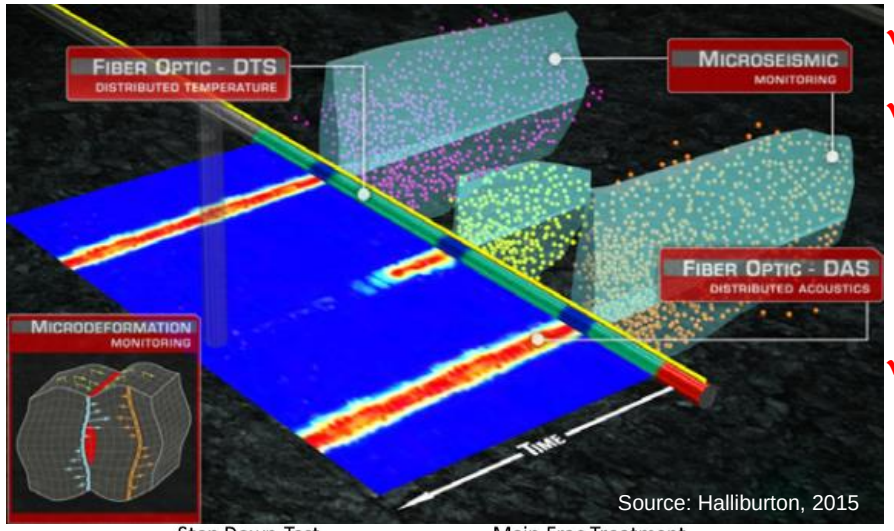
Source: SPE 191864

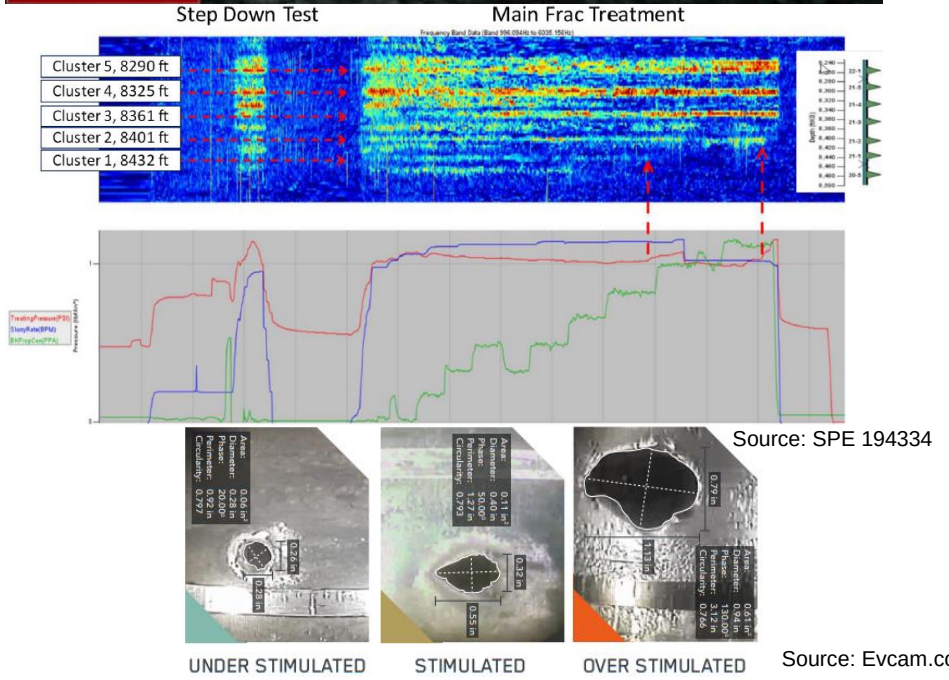


Source: SPE 173323

- ✓ Where do we come from?
  - Conventional hydraulic fracturing dominated by x-linked fluids
  - Relatively small volumes of frac fluid but costly (~5:1 XL vs SW cost)
  - Leak-off is an issue as permeability is relatively high
- ✓ Unconventional approach (very low permeability)
  - Low proppant concentration and huge frac fluid volumes ask for different fluids customized to transport proppant and reduce friction at low overall cost. High pumping rate provides some carrying capacity
  - Slick water is useful for low proppant concentration (< 2ppg). Cheap
  - Hybrid designs including slick water, linear gel and x-linked gels when higher concentrations are required. Balanced cost but operationally challenging as products are different
- ✓ Evolution
  - High Viscosity Friction Reducers (HVFR). A single product can behave as slick water at low concentration and as a x-linked fluid at higher concentrations, but it does not require crosslinkers
  - Viscosity and elasticity are important for proppant transportation
  - Simple chemistry, logistics and field operations. Use of produced water

Technology Enablers – Frac Monitoring





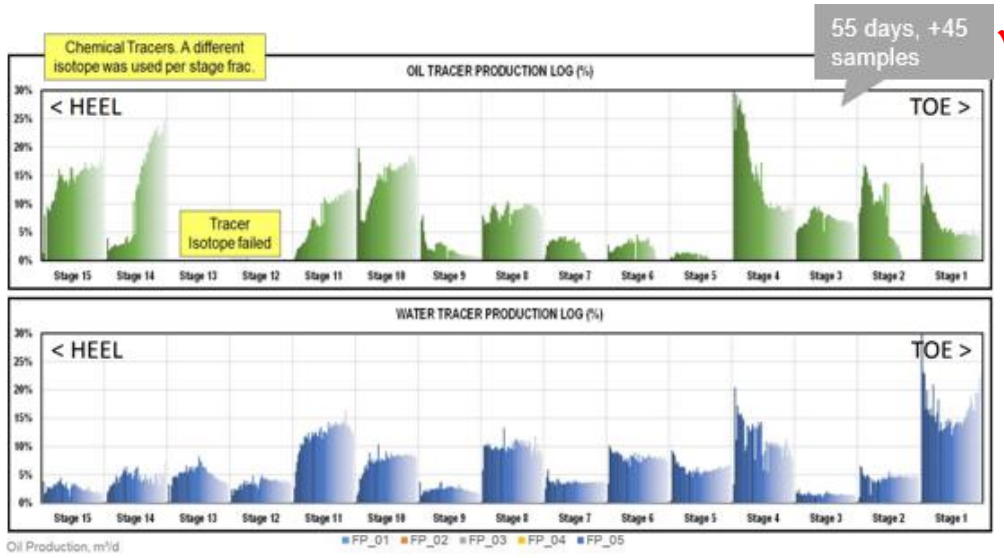
Source: SPE 194334

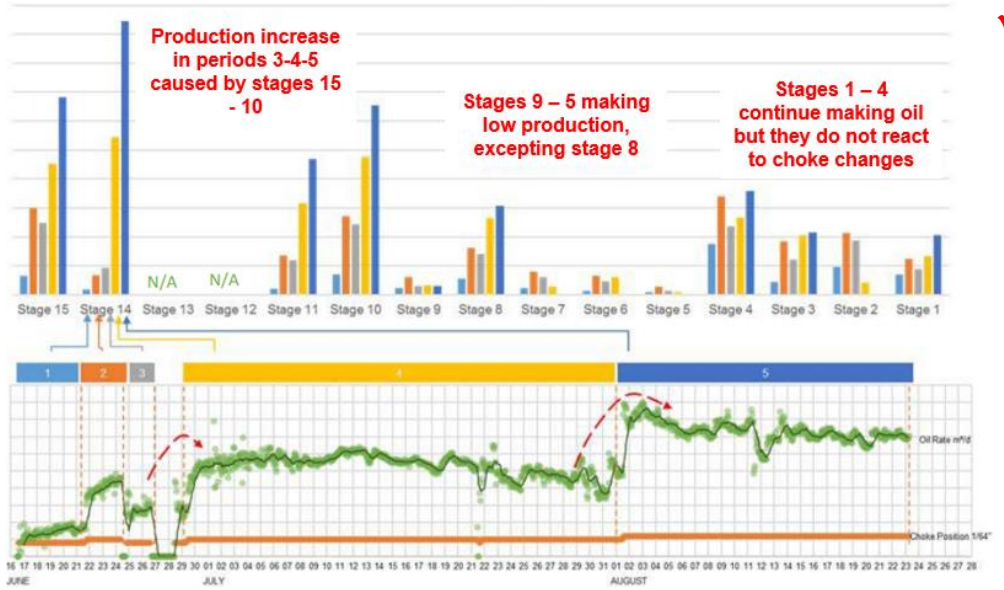
Source: Evcam.com

- ✓ You cannot control what you do not measure!
- ✓ Even if more clusters provide larger contact area, trying to break down and making them to accept even distribution of frac treatment is a major challenge. Cluster efficiency decreases with cluster number
  - Cluster engineering is the key process behind production results
- ✓ Tools and techniques (not all are listed):
  - Not many tools can measure individual cluster production
  - Fiber optics (DTS/DAS) is probably the best technology we have so far
  - PLT can be used as well but it is intrusive and most of the times there are limitations in measuring low rates
  - Downhole camera can be tricky as an eroded hole is a not always a point where a fracture was initiated
  - Tracers are an alternative to test different designs in the same well, but they do not provide rate per individual cluster

Source: Halliburton, 2015

Technology Enablers – Tracers





Source: Panichelli et al, 2017

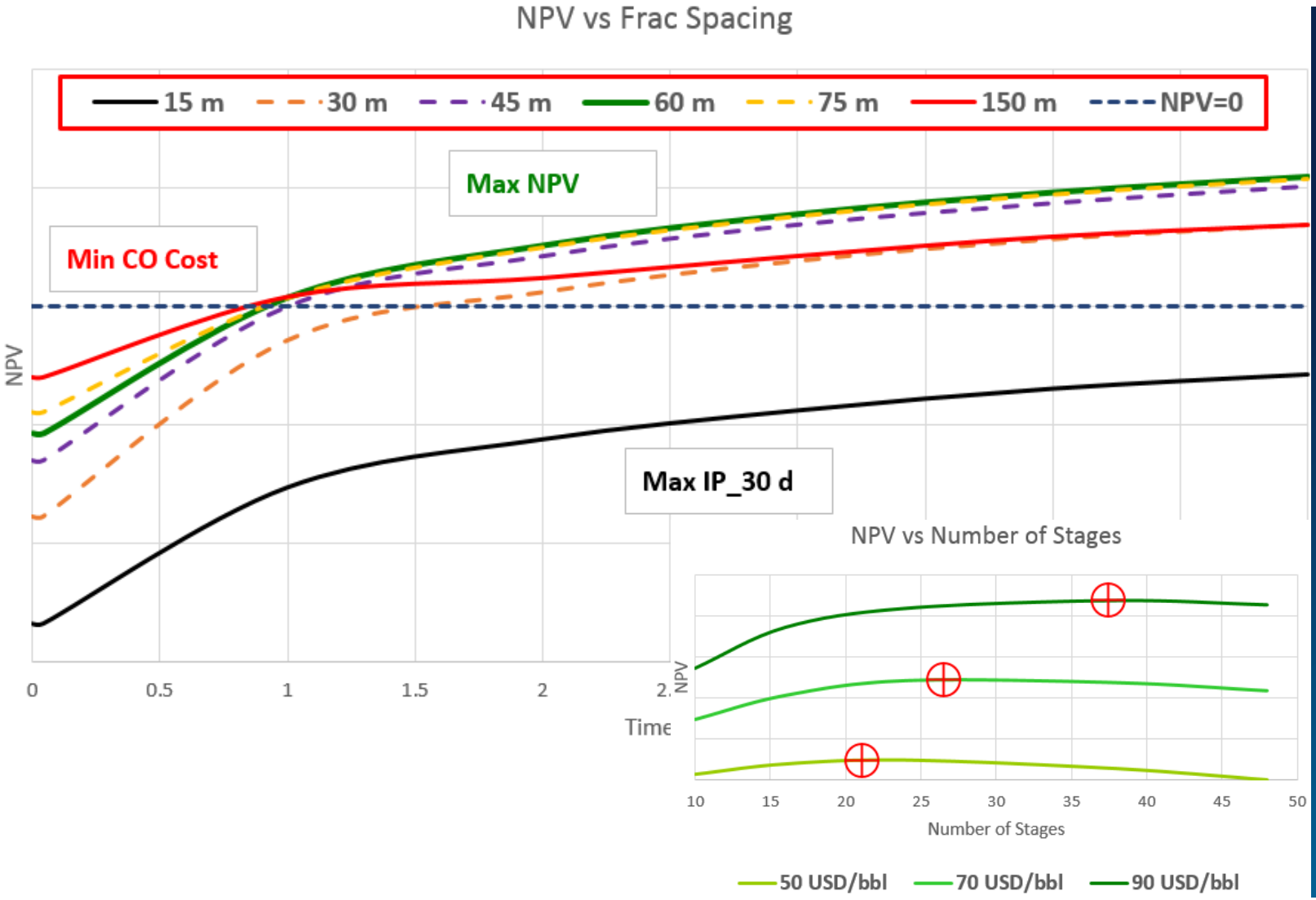
✓ Basics

- Chemical tracers. Liquid or solid water-based, oil-based and gas-based to measure each produced phase
- Injected while pumping hydraulic fractures with minimum disturbance at constant concentration. If possible one distinctive tracer per frac stage and a global one for all stages intended to measure water
- Tracers do not react or adsorb with either frac additives or rock
- Fluid samples taken during production provides insights about production evolution. Non-intrusive technology

✓ What we get

- Evolution of production of each phase per frac stage
- Understanding of clean-up period
- Response of frac stages to operating changes (e.g., chokes). Chole management strategy optimization
- Distinction between frac and reservoir water
- Interference between wells (optimization of well spacing)
- Insight about frac effective production length
- Enhancement of frac designs

Positive Well Economics = Profitability – This Never Changes!



Key drivers

- Profitability is the main driver for a successful development
- All other aspects underpin the primary driver
- Do not focus on highest IP nor lowest well cost
- Oil and gas prices are key components of economics so have a clear picture of the boundaries before it is too late
- EUR @ 30 yr. does not make any sense
  - If project does not fly in 3 – 5 yr., think it twice before moving on

Final Quote

"…I never lose, I either win or learn…"

Source: amazon.in

Nelson Mandela

Q & A Session

Source: chartcons.com

Source: latinschool.org

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