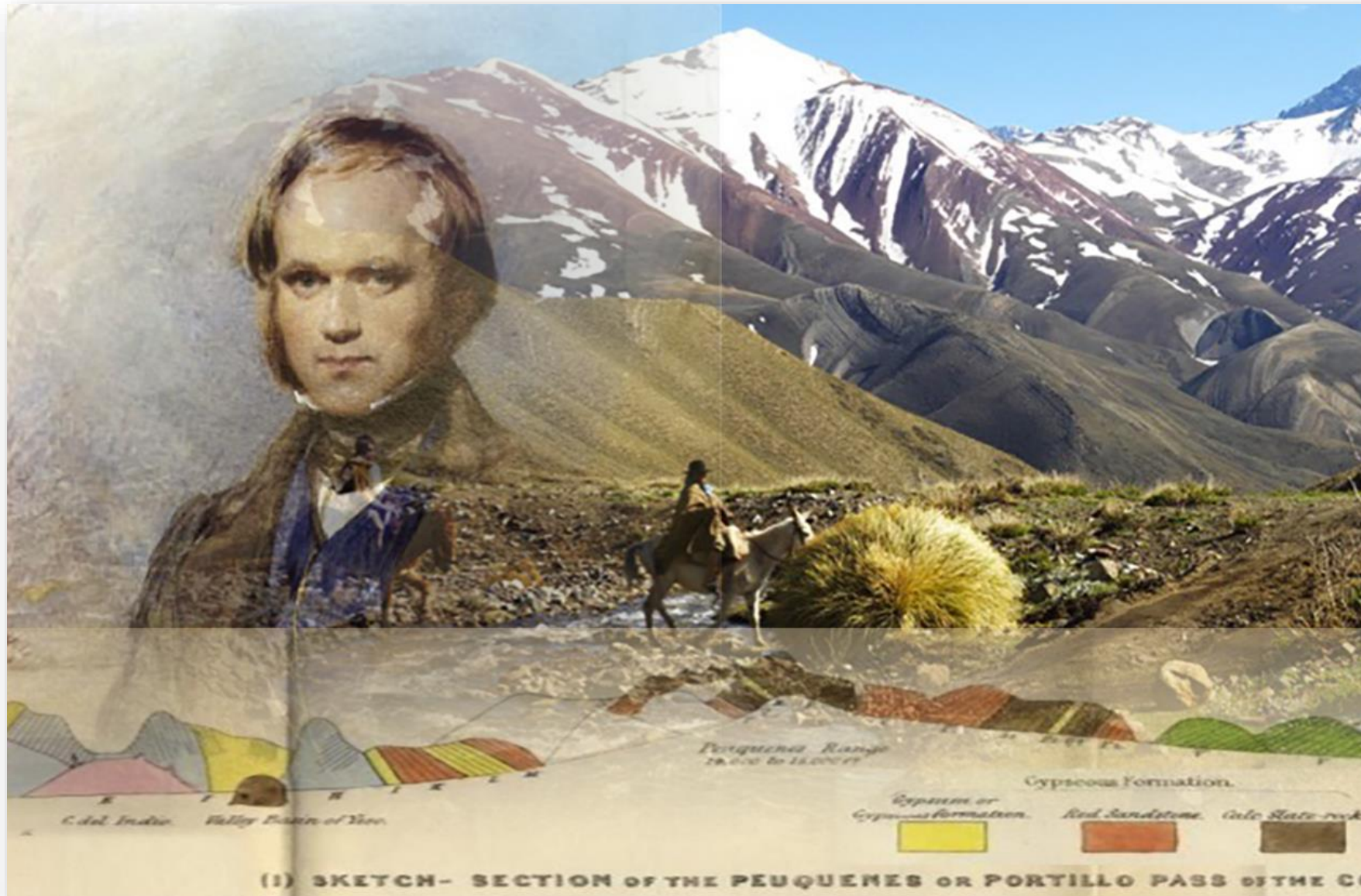


The Discovery of Vaca Muerta

Carlos Macellari

Discovery Thinking Forum
“Pioneering Discoveries” Driving Prosperity

Vaca Muerta First Sighting



First observations by Darwin in the High Cordillera of Mendoza (Piuquenes pass),

Vaca Muerta today

LA NACION

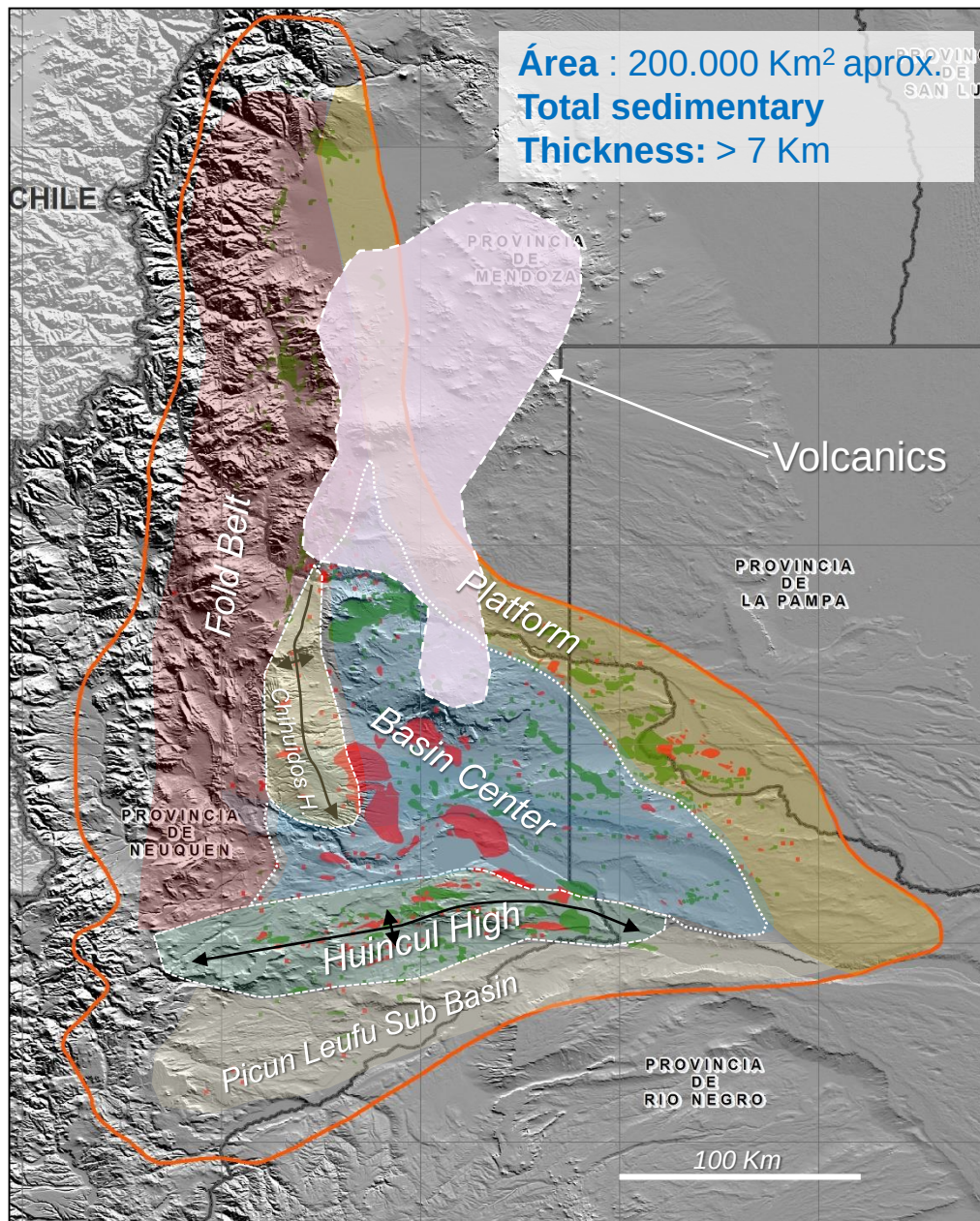
Vaca Muerta marcó el encuentro entre Macri y Trump



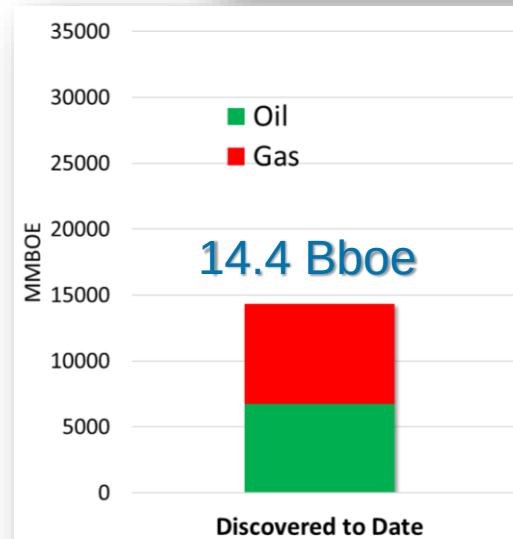
Nov. 30, 2018

A photograph of a steep, dark volcanic slope, likely composed of basaltic lava flows. The surface shows distinct horizontal layering and a rough, textured appearance. Sparse green vegetation is visible along the top edge and in the bottom right corner. The sky is a clear, bright blue.

What is Vaca Muerta?



Neuquén Basin

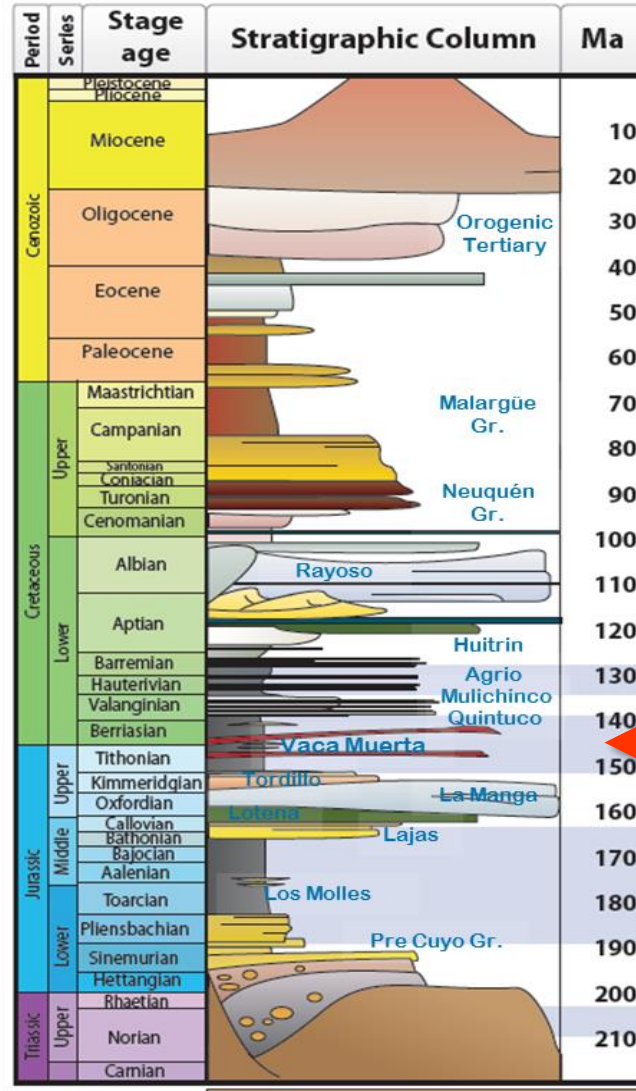


Vaca Muerta Characterization



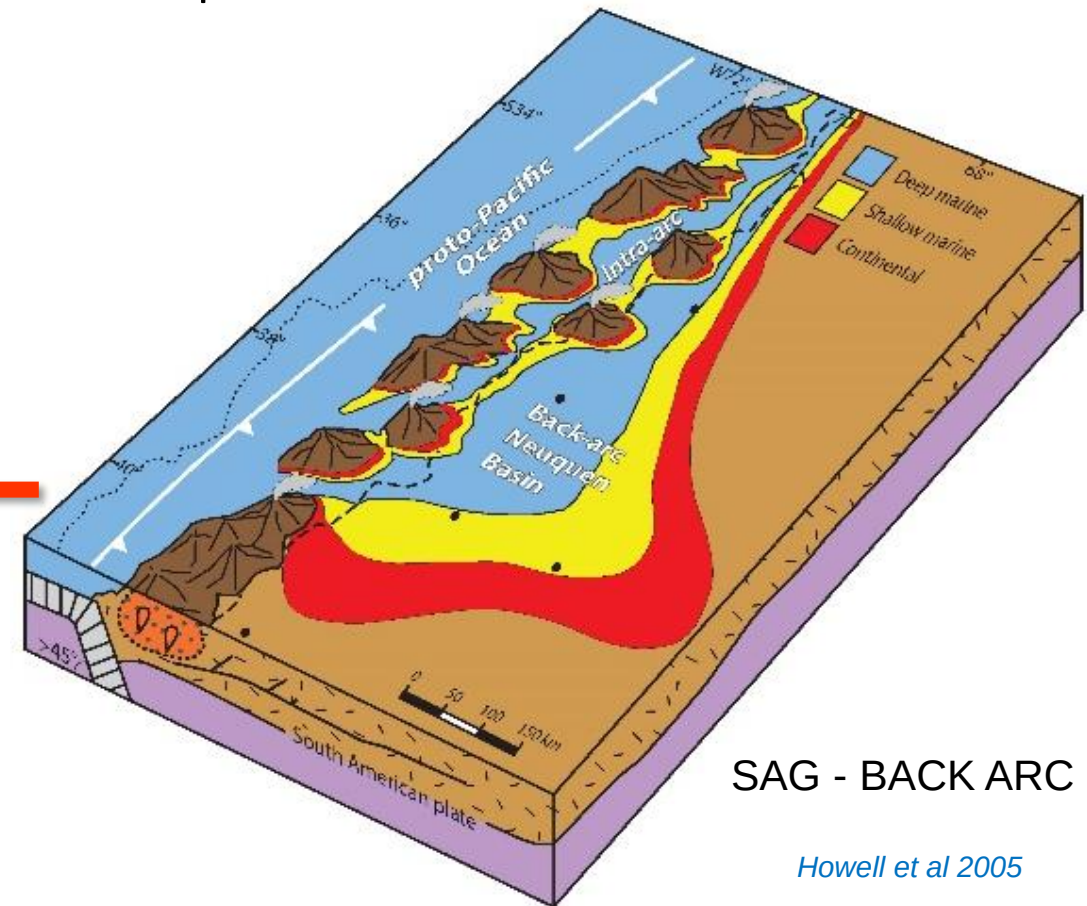
- Great Areal Extent (30.000 km²)
- Large thickness of organic rich section (30 - 400 m) allowing multiple navigation horizons.
- Good Porosities (4 – 16%)
- Burial depth between 2000 and 3500 m.
- Overpressured (0.75 to 0.85 psi/ft)
- TOC: up to 17%
- Mineralogy and elastic parameters adequate for hydraulic fracturing
- **Only about 20% of hydrocarbons generated were expelled.**

Quintuco-Vaca Muerta Depositional System



Stinco & Mosquera 2002

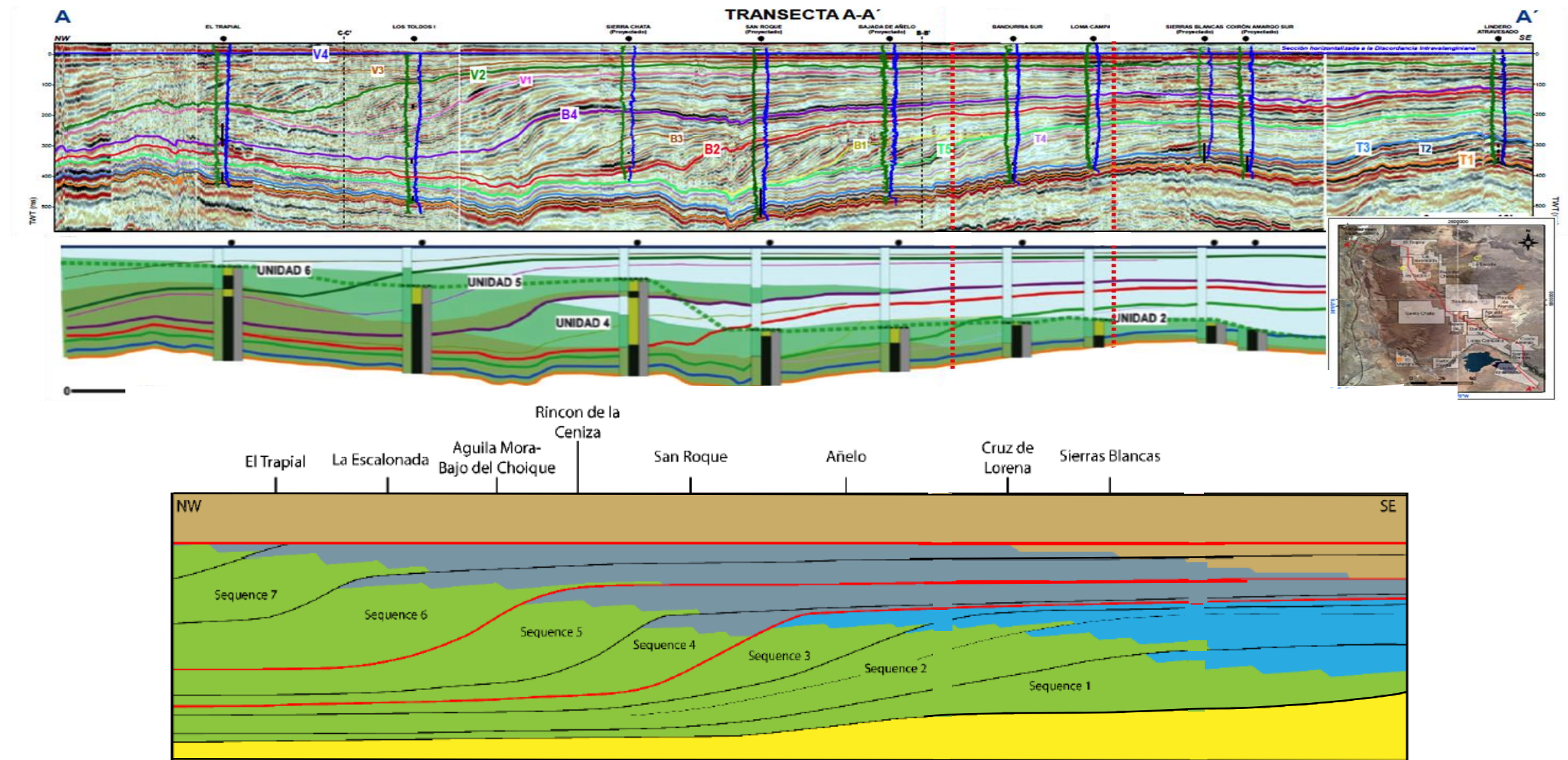
- Mixed clastic-carbonate succession deposited in a shallow to deep marine setting during the Tithonian-Berriasian time.
- Thickness reaches up to ~1000 m.



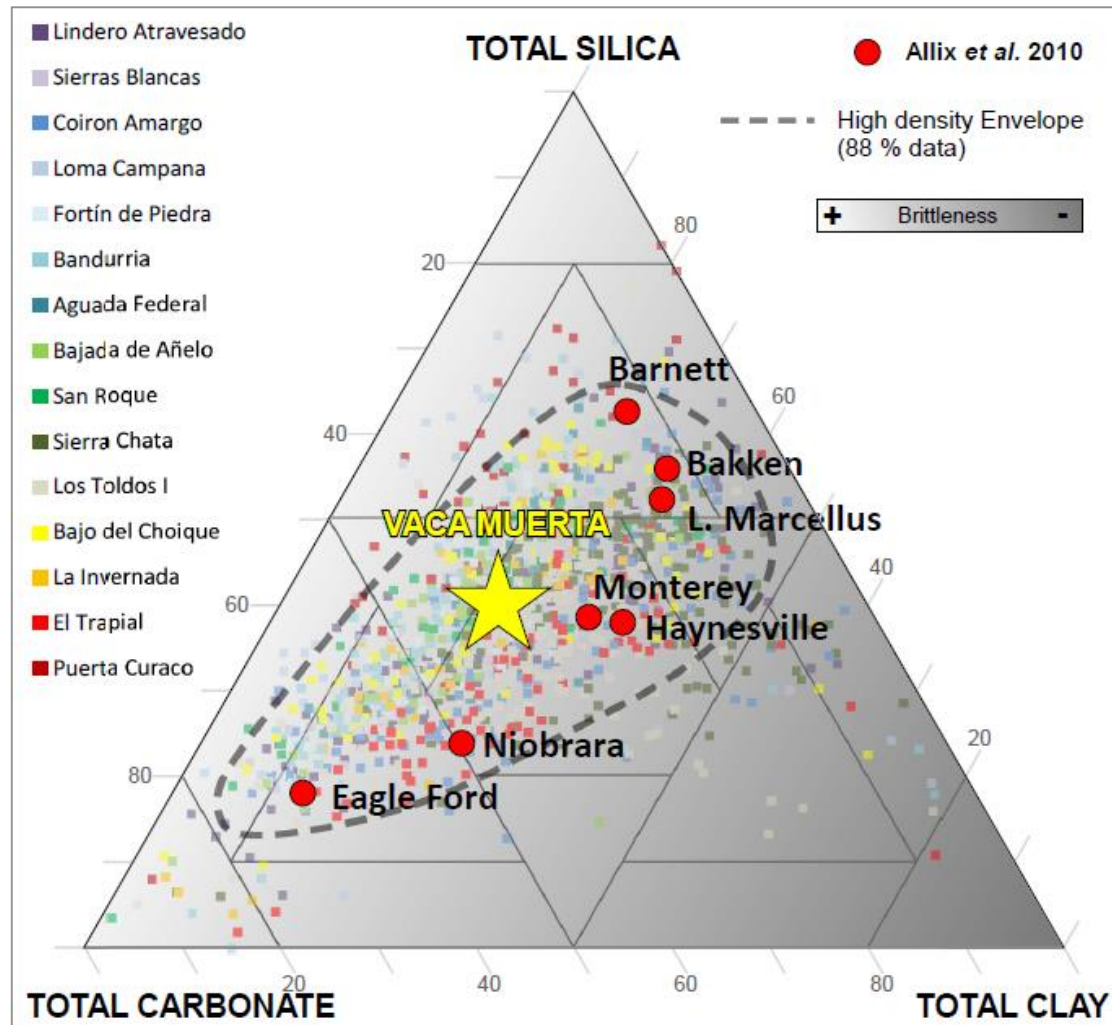
SAG - BACK ARC

Howell et al 2005

Quintuco-Vaca Muerta seismic geometries

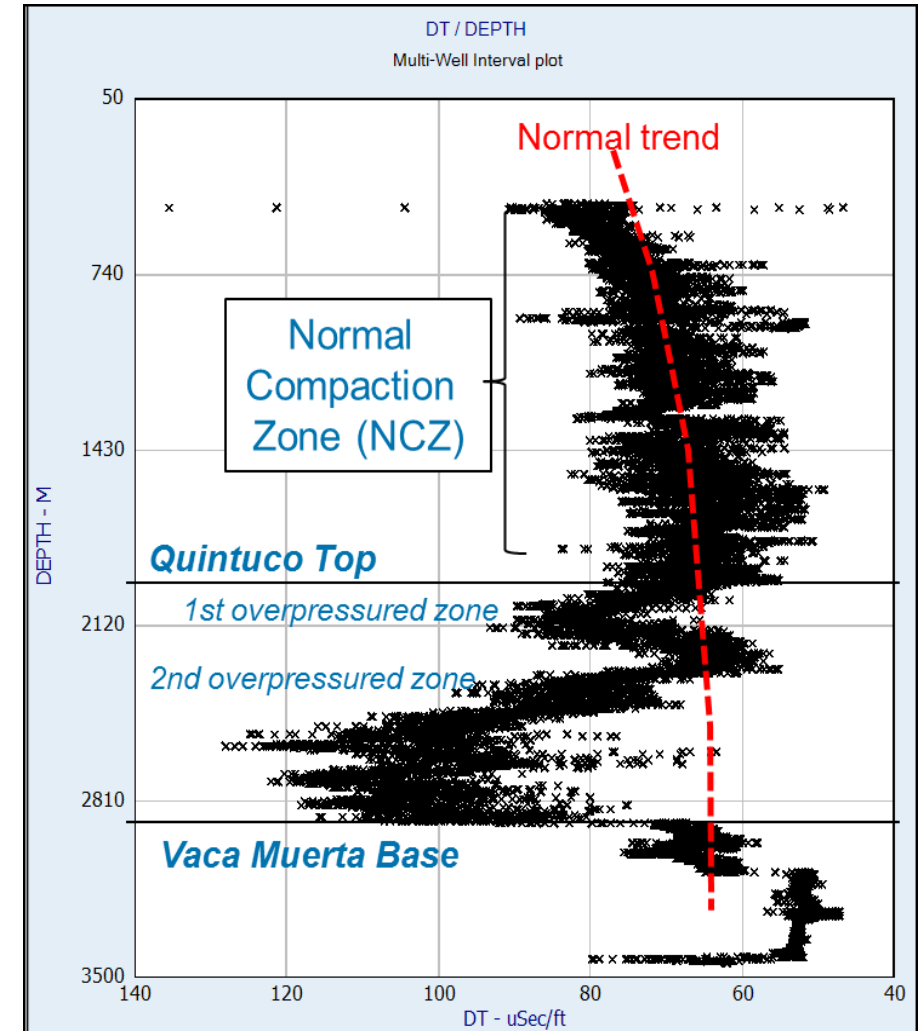
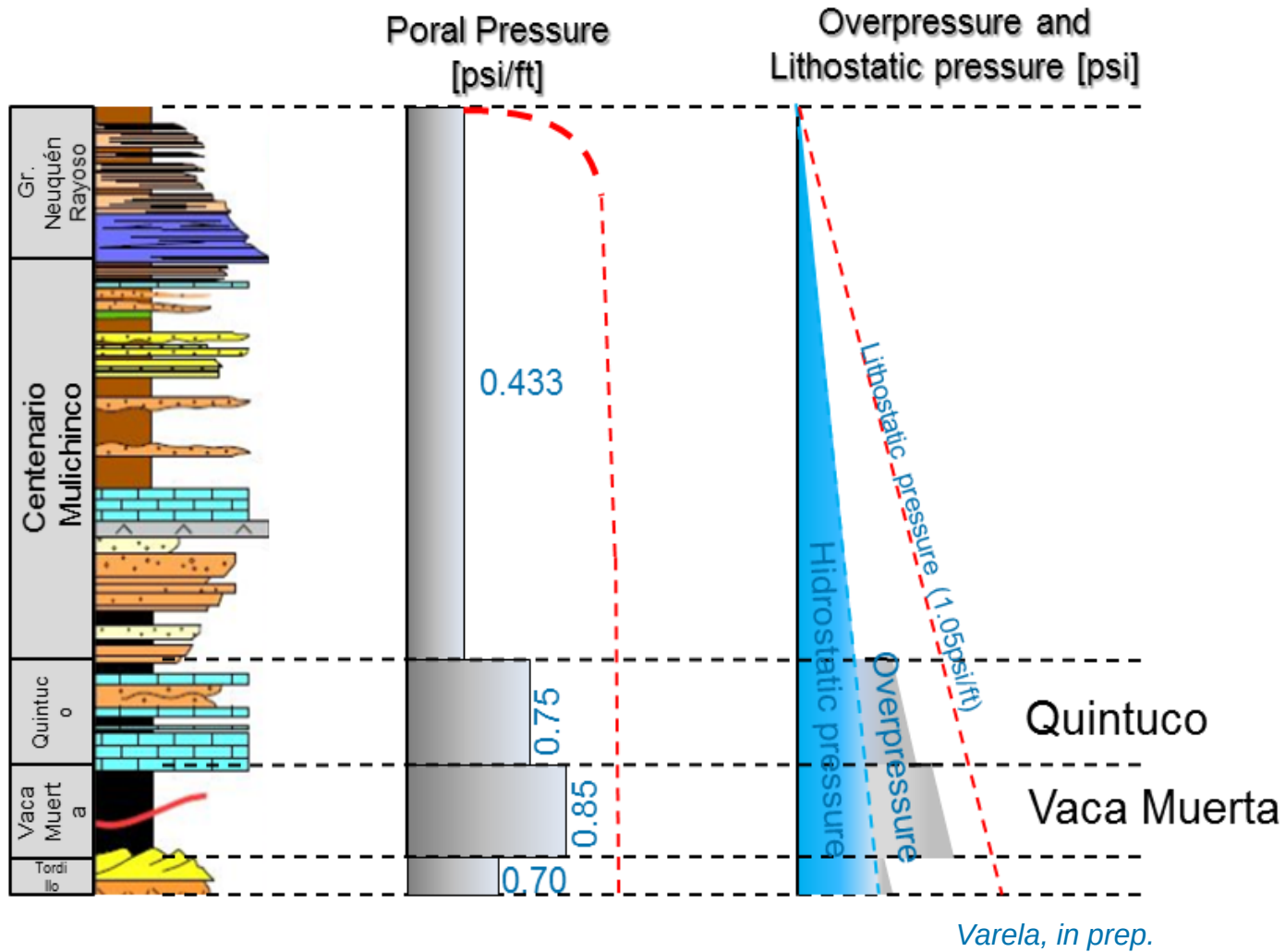


Vaca Muerta Composition



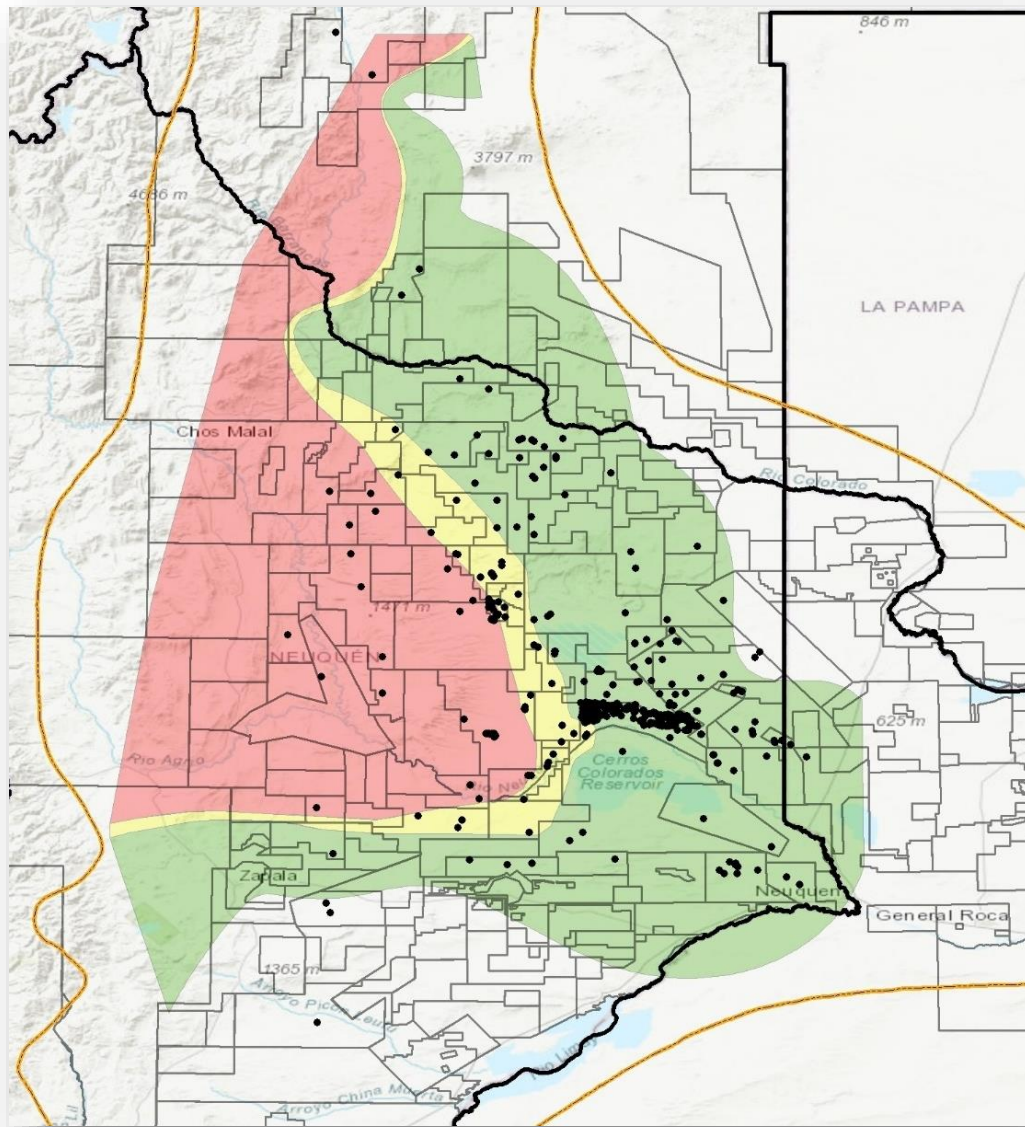
From Marchal et al., 2016

Vaca Muerta - Geopressure



Overpressure barrier in Quintuco helped to retain hydrocarbons within Vaca Muerta

Maturity Zones and wells drilled in Vaca Muerta



-  Dry Gas Window
-  Wet Gas Window
-  Oil Window
-  Vaca Muerta well

Aproximately 1000 wells drilled to date



Evolution of Vaca Muerta



The first description of marine Tithonian



Guillermo Bodenbender
(1857 – 1941)



Virgatospinctes mendozani

Salado River Region in Southern Mendoza

“The Lower limestone group is very bituminous and almost completely impregnated by kerosen, which has been found in liquid state in the cental cavity of an ammonite.....” (1892)

From Leanza, 2012

The definition of Vaca Muerta

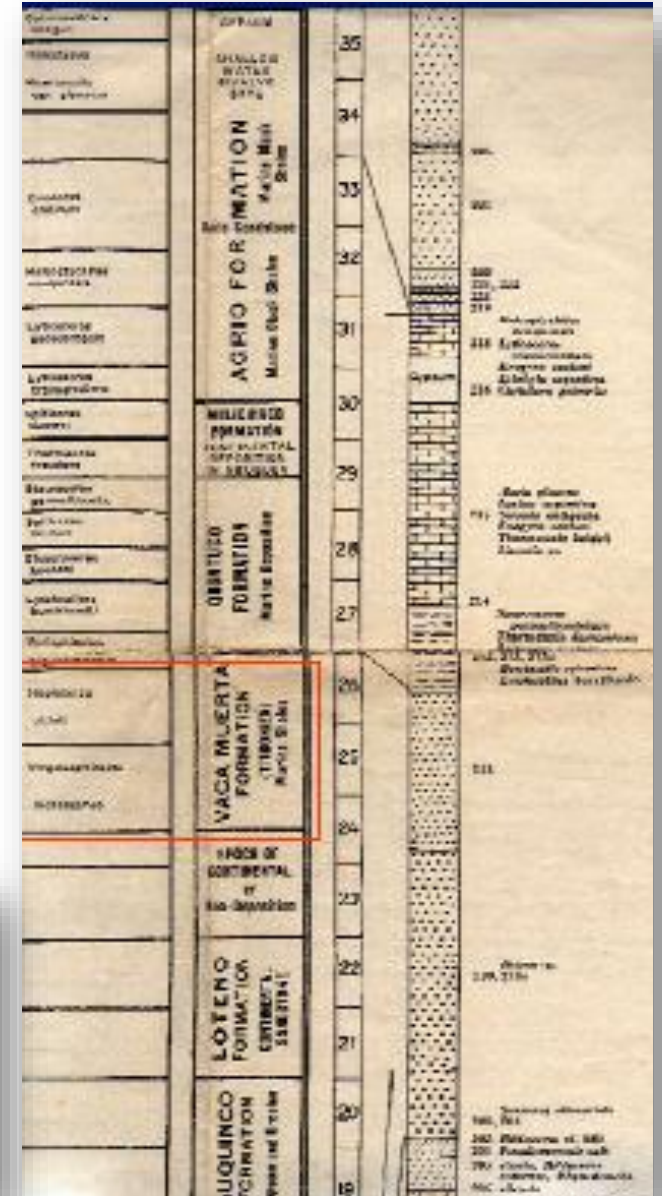


Charles Weaver
(1880 – 1958)

The Tithonien strata in northern Neuquen are dark gray calcareous shales rather firmly indurated and exhibiting considerable jointing. There is very little variation in the lithology from base to top. In Cerro Loteno and Picun Leufú the formation decreases in thickness from 800 meters to 200 and consists mainly of brownish gray calcareous shales and yellowish brown clays.

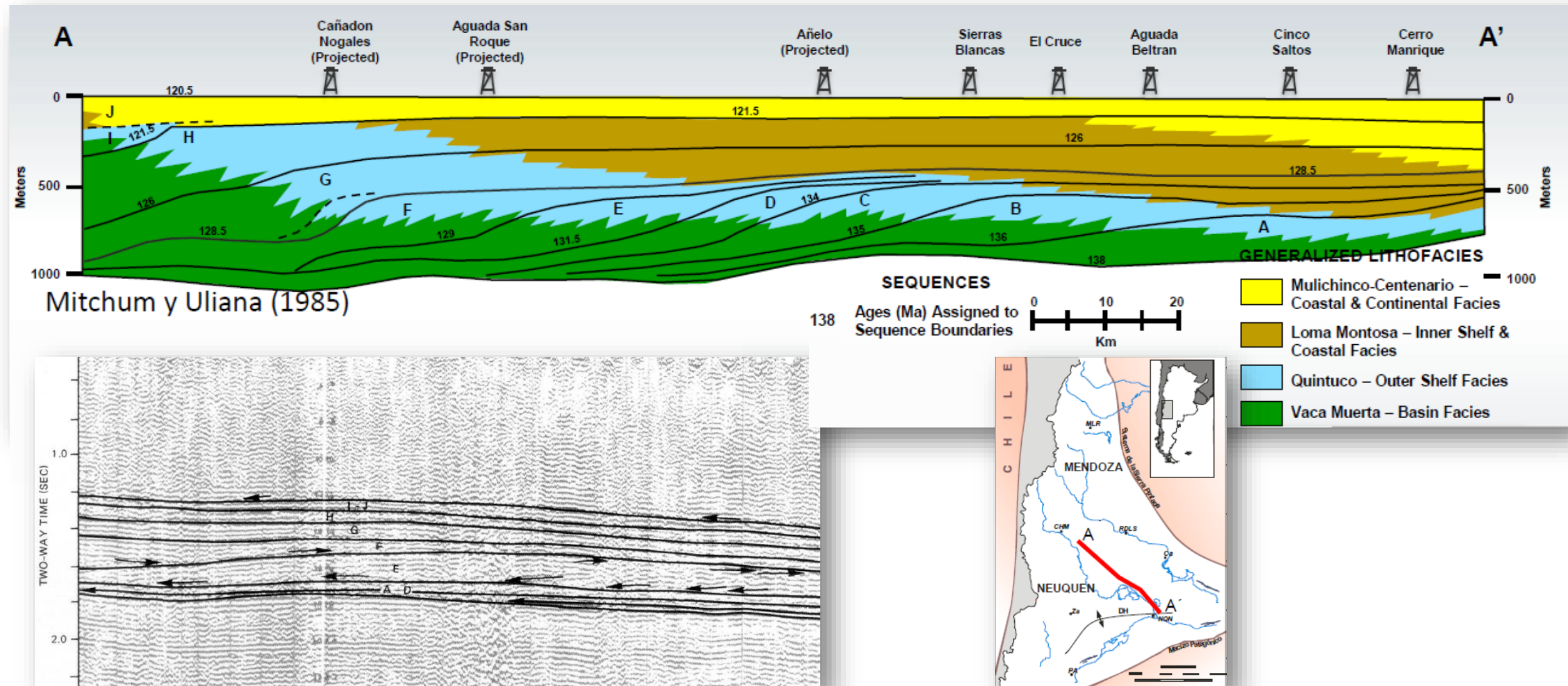
The lower 25 meters consists of thinly bedded black shales at Vaca Muerta and Lago Auquincó and lighter brown sandy clay shales at Cerro Loteno and Picun Leufú. It rests conformably upon the lower Malm conglomerates and sandstones below, but with a very sharp lithologic break.

Weaver (1931)

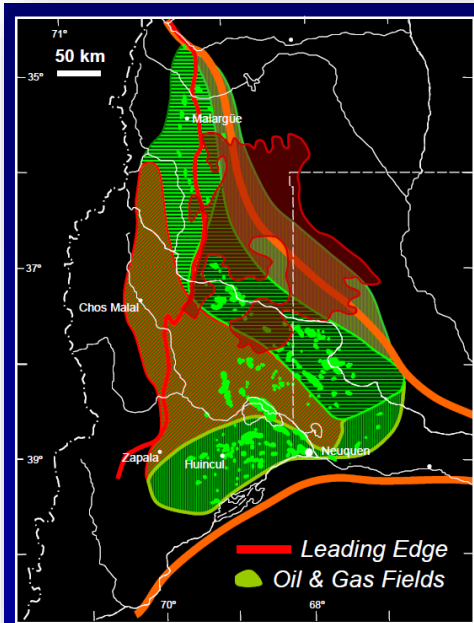
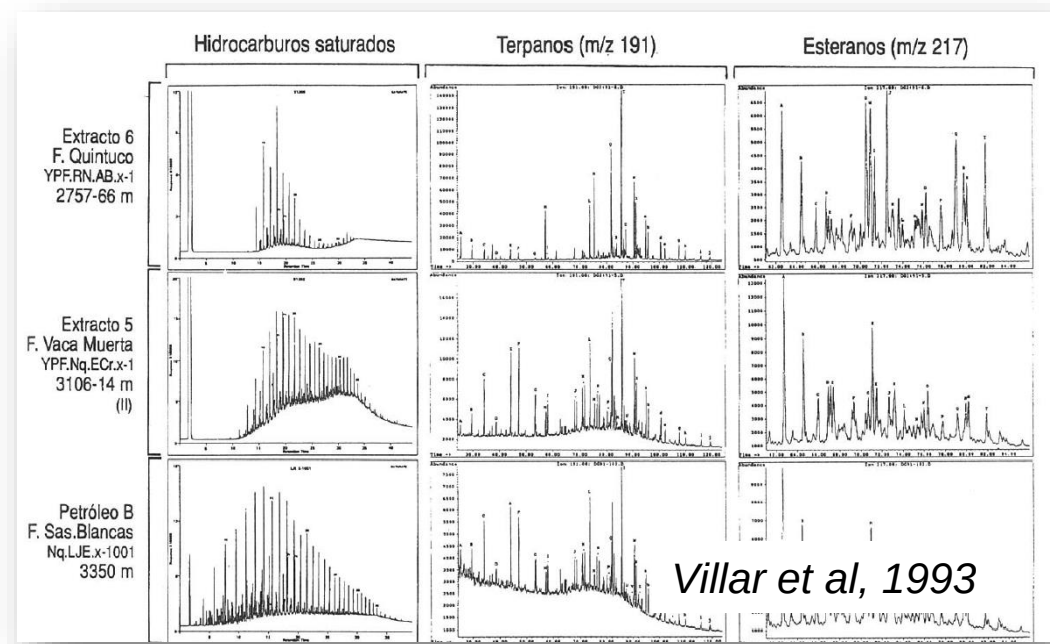


The Stratigraphic Framework of Vaca Muerta

Mitchum and Uliana 1985



Vaca Muerta as a Source Rock



Hydrocarbon Accumulations

	CUM	Rem.	EUR
Gas (TCF)	12.37	17.53	29.90
Oil (BBls)	2.80	1.58	4.38

Yet To Find Resources

Gas (TCF)	12.00 to 23.50
Oil (BBls)	0.70 to 1.70
Heavy Oil (BBls)	1.20 to 2.50

Legarreta et al, 2003

Basin	Source Rock Unit		Hydrocarbons		Current GAE (%)
			Generated (Bkg)	In-place (Bkg)	
Neuquen	Vaca Muerta	All the basin	980,000	1700	0.2
		Basin Center	9,273	600	6.5
Maracaibo	La Luna-Misoa (!)		250,000	35,220	14.1

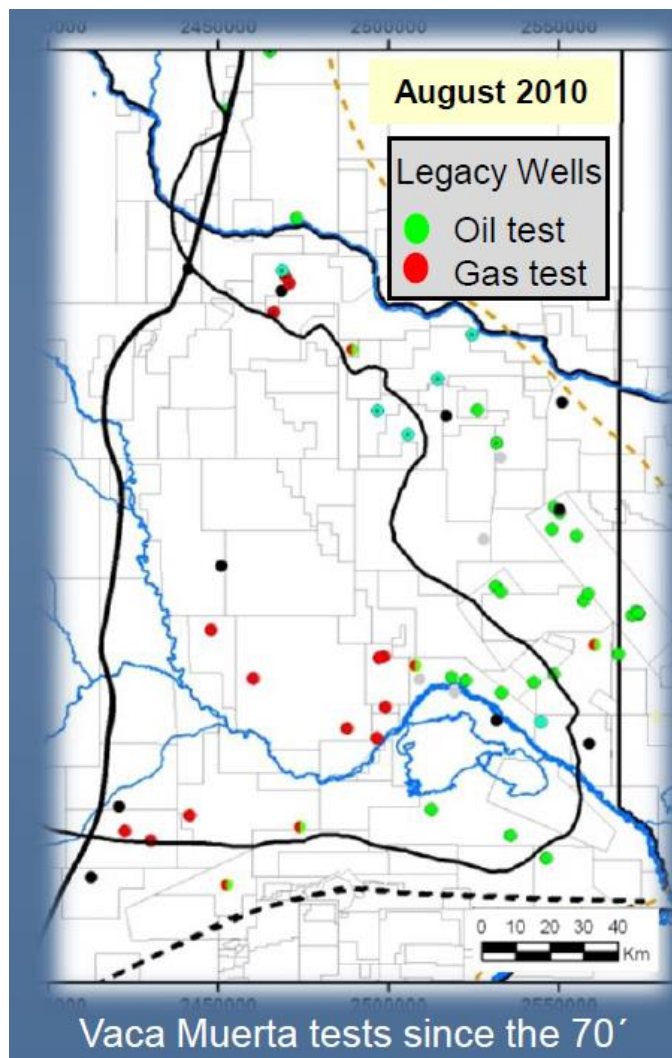
GAE = Generation-Accumulation Efficiency

Legarreta et al, 2003

Evolution of Vaca Muerta



Hints from Legacy wells



More than 130 wells were identified with tests or cores in the Vaca Muerta Marls

YPF.Nq.IAJ.x-1



YPF.Nq.LCa.e-2 1980

grada en su parte inferior por un paquete de marga gris oscuro y arcillita gris, compacta, calcárea, en parte limosa, subordinada.- Al ser perforado este paquete se constataron manifestaciones gasíferas.- En 2502 mbbp el detector acusó más de 100.000 divisiones (fuera de escala), posteriormente fue evaluado a pozo entubado (intervalo 2507/09 - 2502/05 mbbp) donde se midió un caudal de 73.272 m³/d de gas combustible y 1,440 m³/d de condensado por orificio de 14 mm, presión dinámica: 28 kg/mm², indicando este resultado una falta de permeabilidad efectiva en el reservorio.-

YPF.Nq.VN.x-1 1981

Resultado final: Pozo exploratorio descubridor.-
Km. Quintuco + Vaca Muerta - Intervalo 2836/40 mbbp.
Producción final: 43,3 m³/d de petróleo y 30848 m³/d de gas por 10 mm (dens. 0,760 a 15°C). A-
gua 0%.-

NqBP_a 7 1983

Final Petrolifero
Ø 80 mm.-
120 m³/d - A: 1% - Pab. 50%
Vaca Muerta Tapon reafirmable
25536 PK 2496 m.

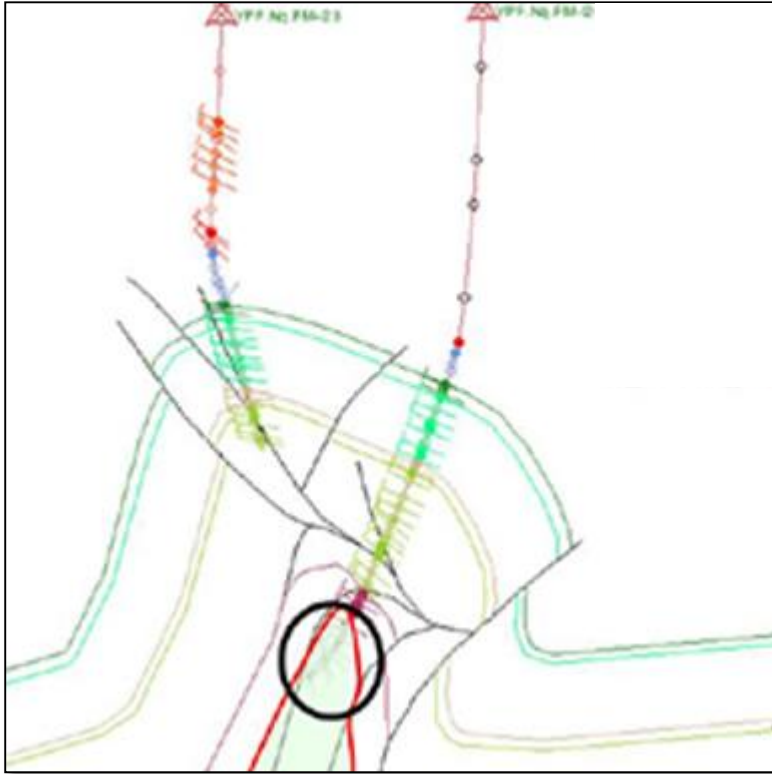
YPF.Nq.DCh.x-2 2001

En 2647 m el pozo entró en surgencia, y se reanudó la perforación con el sistema Under Balance, quemando gas al campo. Las muestras fueron tomadas del separador de este equipo, con abundante derrumbe que enmascara los cambios litológicos.

From Lanuse, 2017

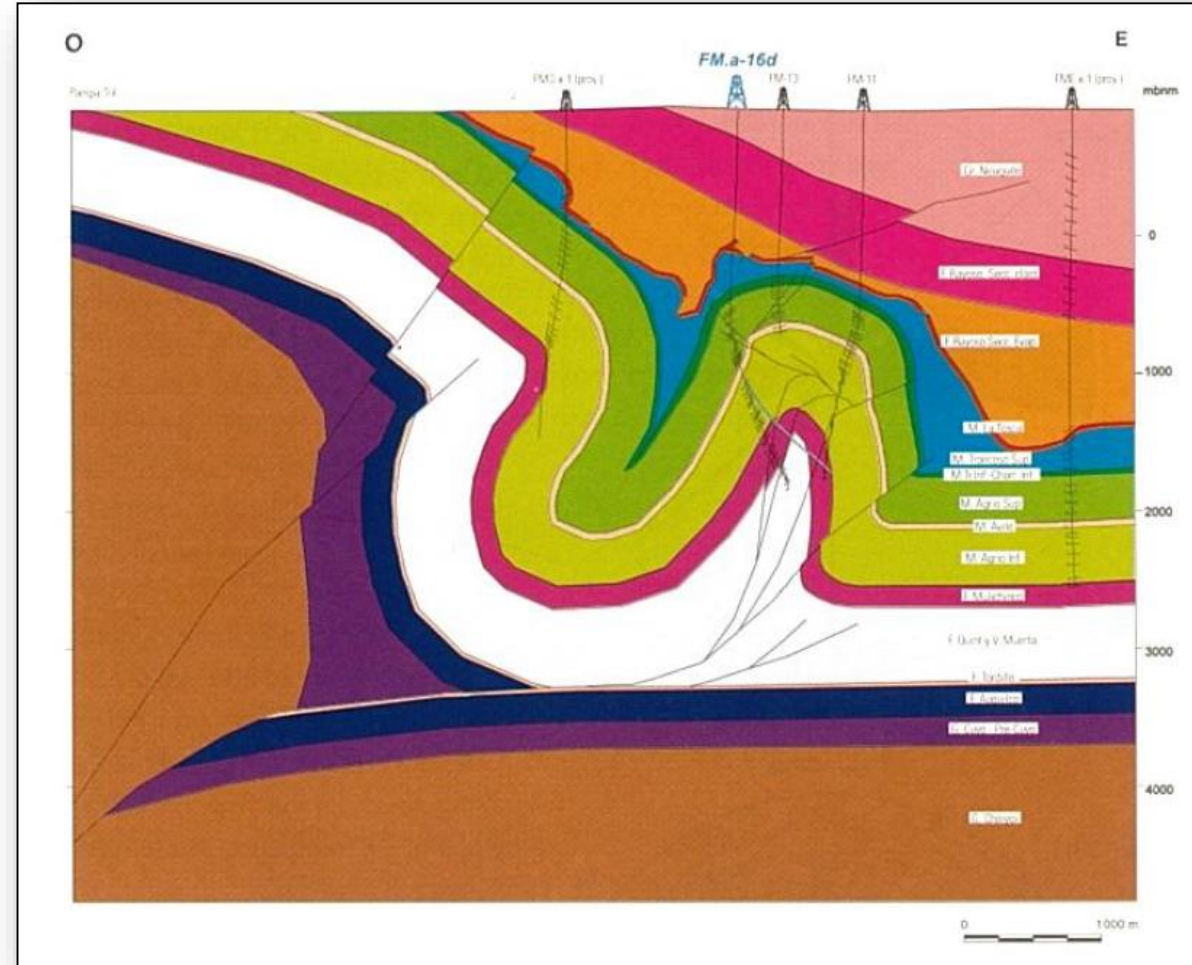
First Oil Production from Vaca Muerta

YPF-FM-25



FM-25 – Filo Morado

Produced 533,000 bo from fractured Quituco-Vaca Muerta between 1991 and 1995



EIA World Shale Gas and Shale Oil Resource Assessment - 2013

Table V-1A. Shale Gas Reservoir Properties and Resources of Argentina

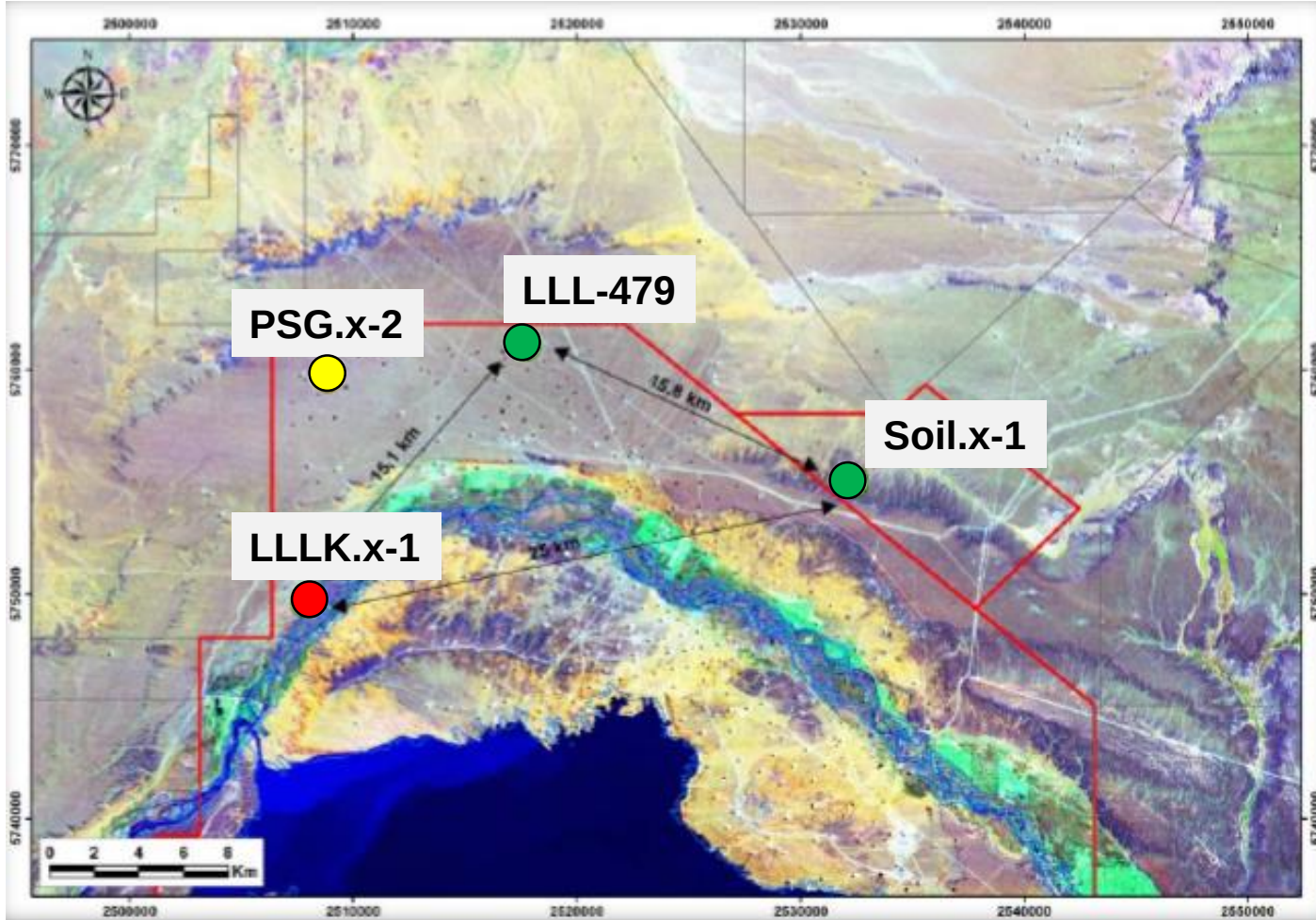
Basic Data	Basin/Gross Area		Neuquen (66,900 mi ²)					
	Shale Formation		Los Molles			Vaca Muerta		
	Geologic Age		M. Jurassic			U. Jurassic - L. Cretaceous		
	Depositional Environment		Marine			Marine		
Physical Extent	Prospective Area (mi ²)		2,750	2,380	8,140	4,840	3,270	3,550
	Thickness (ft)	Organically Rich	800	800	800	500	500	500
		Net	300	300	300	325	325	325
	Depth (ft)	Interval	6,500 - 9,500	9,500 - 13,000	13,000 - 16,400	3,000 - 9,000	4,500 - 9,000	5,500 - 10,000
Average		8,000	11,500	14,500	5,000	6,500	8,000	
Reservoir Properties	Reservoir Pressure		Highly Overpress.	Highly Overpress.	Highly Overpress.	Highly Overpress.	Highly Overpress.	Highly Overpress.
	Average TOC (wt. %)		2.0%	2.0%	2.0%	5.0%	5.0%	5.0%
	Thermal Maturity (% Ro)		0.85%	1.15%	2.20%	0.85%	1.15%	1.50%
	Clay Content		Low/Medium	Low/Medium	Low/Medium	Low/Medium	Low/Medium	Low/Medium
Resource	Gas Phase		Assoc. Gas	Wet Gas	Dry Gas	Assoc. Gas	Wet Gas	Dry Gas
	GIP Concentration (Bcf/mi ²)		49.3	118.0	190.1	66.1	185.9	302.9
	Risked GIP (Tcf)		67.8	140.4	773.8	192.0	264.8	645.1
	Risked Recoverable (Tcf)		8.1	35.1	232.1	23.0	91.2	193.5

307 TCF

Basic Data	Basin/Gross Area		Neuquen (66,900 mi ²)			
	Shale Formation		Los Molles		Vaca Muerta	
	Geologic Age		M. Jurassic		U. Jurassic - L. Cretaceous	
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	Depth (ft)	Interval	6,500 - 9,500	9,500 - 13,000	3,000 - 9,000	4,500 - 9,000
Average		8,000	11,500	5,000	6,500	
Reservoir Properties	Reservoir Pressure		Highly Overpress.	Highly Overpress.	Highly Overpress.	Highly Overpress.
	Average TOC (wt. %)		2.0%	2.0%	5.0%	5.0%
	Thermal Maturity (% Ro)		0.85%	1.15%	0.85%	1.15%
	Clay Content		Low/Medium	Low/Medium	Low/Medium	Low/Medium
Resource	Oil Phase		Oil	Condensate	Oil	Condensate
	OIP Concentration (MMbbl/mi ²)		36.4	9.2	77.9	22.5
	Risked OIP (B bbl)		50.0	11.0	226.2	44.2
	Risked Recoverable (B bbl)		3.00	0.66	13.57	2.65

16.2 B bbl

First Vaca Muerta Wells – Repsol YPF



PSG.x-2 - 2009

- First well in Loma La Lata geared to test VM **Shale Gas**
- Discovered oil from Upper and Lower Quintuco

LLLK.x-1 – 2010

- Targeted to karstic features in Lower Quintuco
- Deepened to Vaca Muerta due to poor results in objective
- First Shale Gas well (2 fracs)

LLL-479 - 2010

- Dry well with target at Lower Quintuco
- Re-entry into Vaca Muerta
- **First discovery of Shale Oil**

Soil.x-1 - 2011

- First well in Loma Campana to evaluate **Shale Oil Play**
- Production from Vaca Muerta, with 5 fractures

Repsol YPF realiza el "mayor descubrimiento de petróleo en la historia" en Argentina

8 noviembre 2011

La petrolera argentina YPF, controlada por el grupo español Repsol, confirmó este lunes la existencia de 927 millones de barriles de petróleo no convencional en el yacimiento de Loma La Lata, en la provincia argentina de Neuquén, el más grande del país.

El descubrimiento se produjo tras analizar volúmenes iniciales de entre 200 y 300 millones de barriles (petróleo no convencional) de alta calidad, que han sido estimados en unos 5.000 millones de barriles equivalentes a los 5.000 barriles de petróleo convencional.

Además, la empresa anunció la definición de una zona productiva de 502 kilómetros cuadrados en la formación Vaca Muerta, una zona de esta zona, con potencialidad de recursos adicionales. Por su parte, Repsol emitió desde Madrid un comunicado en el que asegura que este hallazgo es "el mayor descubrimiento de petróleo en la historia".

ECONOMÍA

Retina CincoDías

Repsol YPF anuncia el mayor descubrimiento de petróleo en la historia



SANTIAGO CARCER | MADRID
7 NOV 2011 - 21:14 CET

Vaca Muerta es el nombre de una formación rocosa de 30.000 kilómetros cuadrados, el equivalente a la superficie de Galicia, en las provincias argentinas de Neuquén y Mendoza. Tiene el nombre mal puesto. Porque nunca una vaca muerta dio para tanto. YPF, la filial argentina de Repsol (57,5% del capital) que gestiona el grupo Perten, del empresario Enrique Eskenazi (25,5%), anunció ayer el que puede ser el mayor hallazgo de petróleo y gas en la historia, tanto de Repsol como de YPF.

The "Discovery"

November 8, 2011

LA NACION

YPF descubrió en Neuquén un "espectacular" yacimiento de petróleo no convencional

Se encontró el equivalente a mil millones de barriles, que significan casi 5 años de producción; exploran otra área con "enorme potencialidad"

8 de noviembre de 2011 • 08:56



Comentar
(1085)



Me gusta

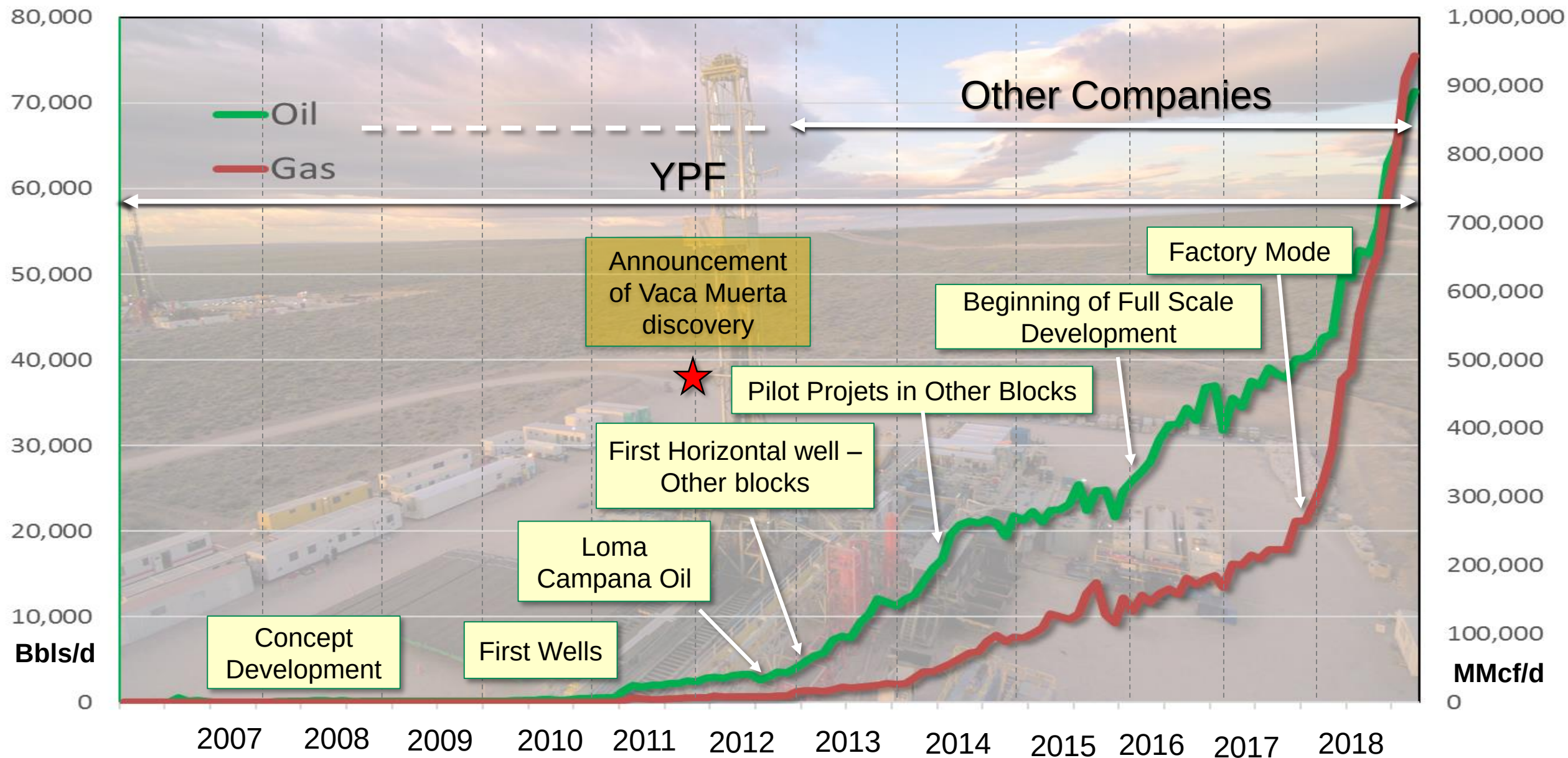


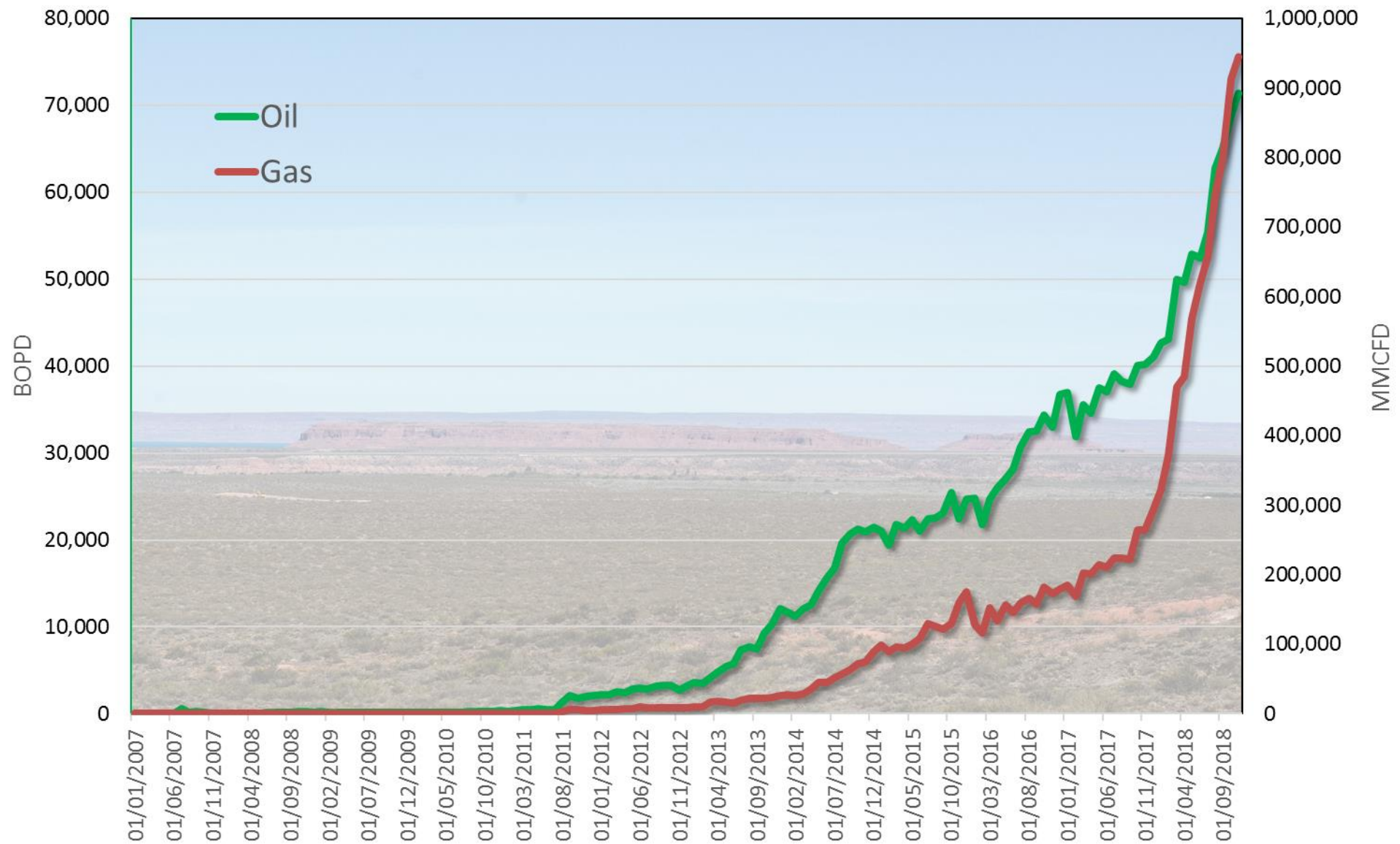
Compartir

La petrolera YPF anunció hoy un "espectacular" descubrimiento de petróleo en Neuquén. Se trata de 927 millones de barriles, que equivalen a casi 5 años de la producción de la empresa en el país.

El hallazgo ocurrió en la formación denominada Vaca Muerta, de una extensión total de 30.000 km², de los que YPF posee 12.000 km². "Además ya hay otra área productiva de 502 km² a explorar que abre una expectativa de grandes volúmenes de hidrocarburos de alta calidad", informaron desde YPF a LA NACION.

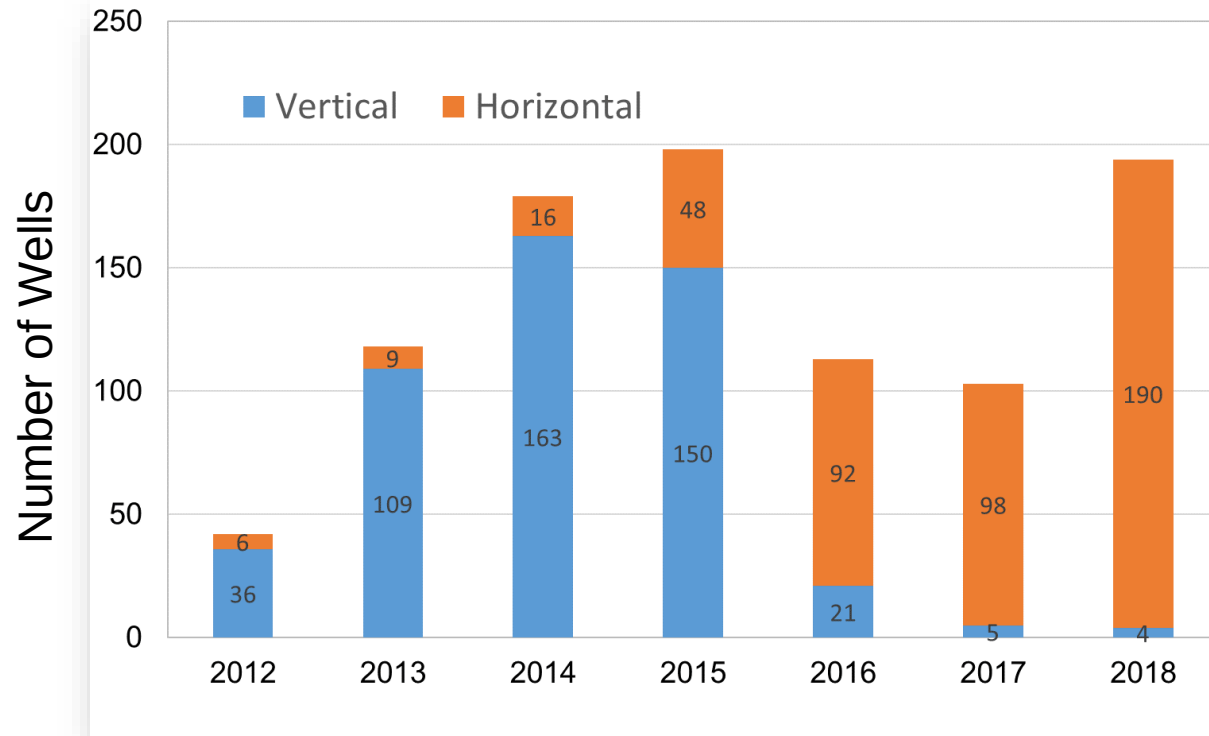
Vaca Muerta as a Reservoir - Production





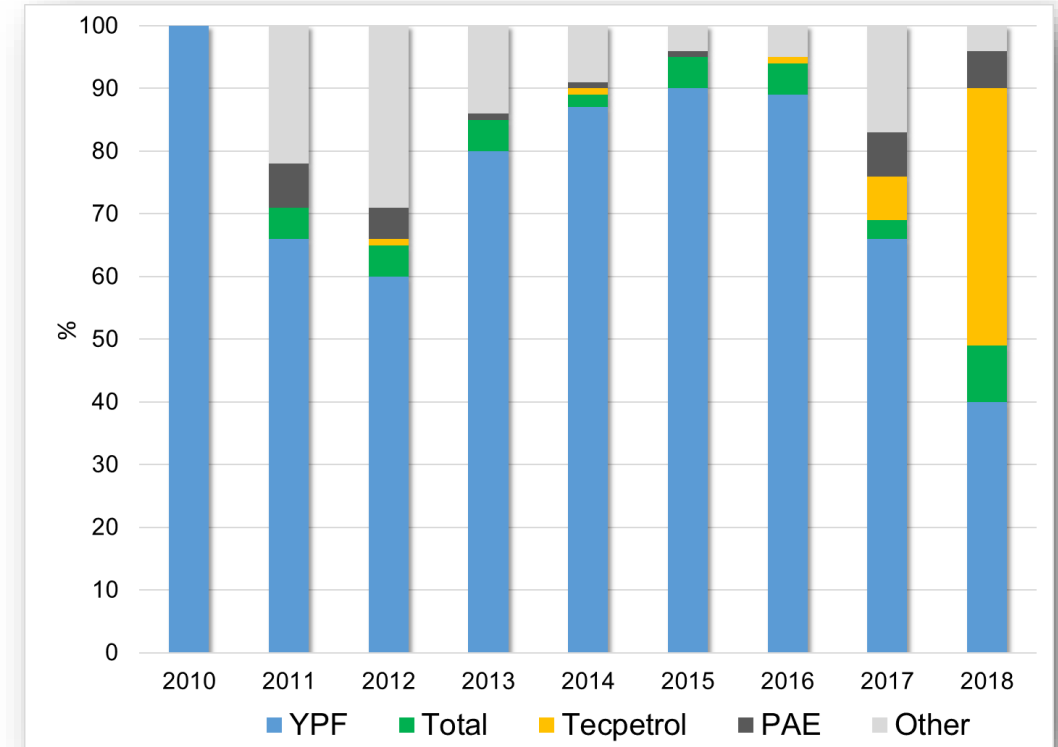
Progression of Vaca Muerta Wells

Vertical → Horizontal



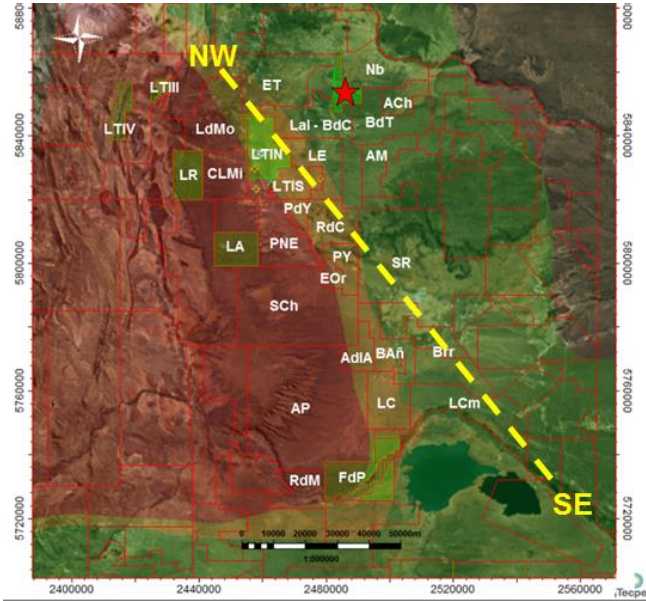
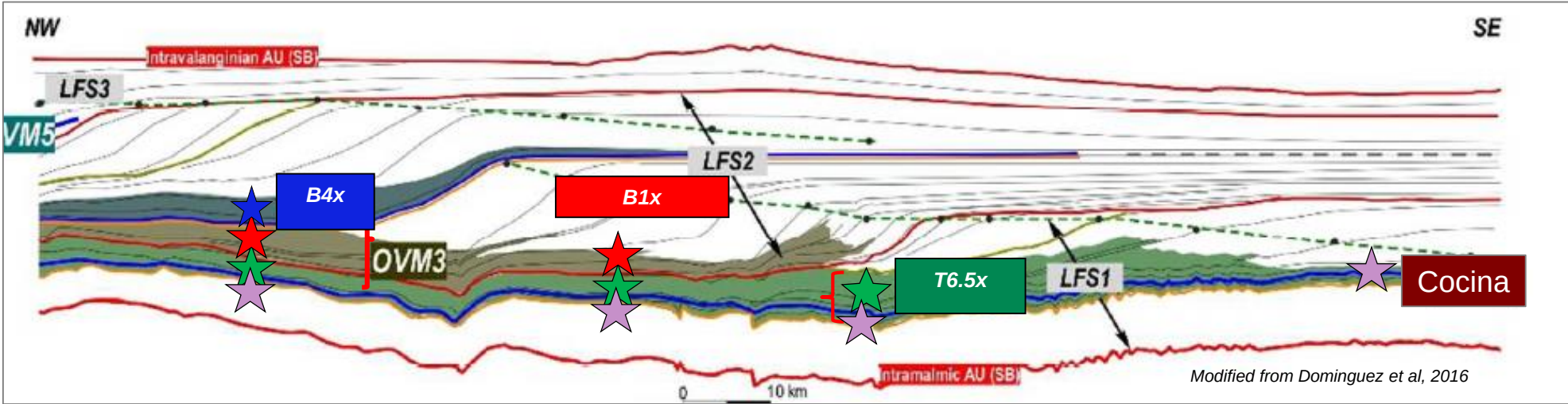
YPF → Other Co's

% Vaca Muerta wells drilled by Co.



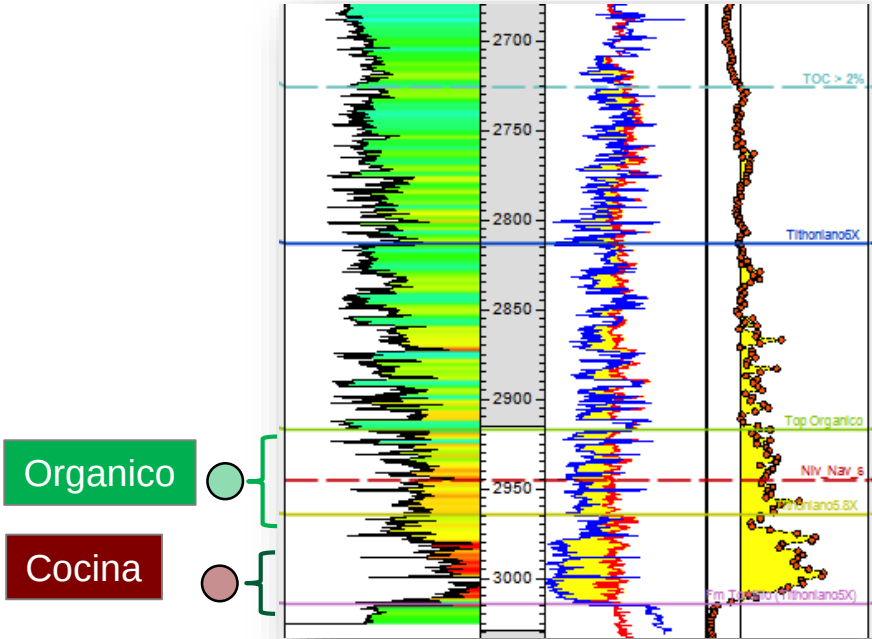
Lateral length from average of 1000m in 2014 to 2200m in 2018

Vaca Muerta System – Evolution of Landing Zones

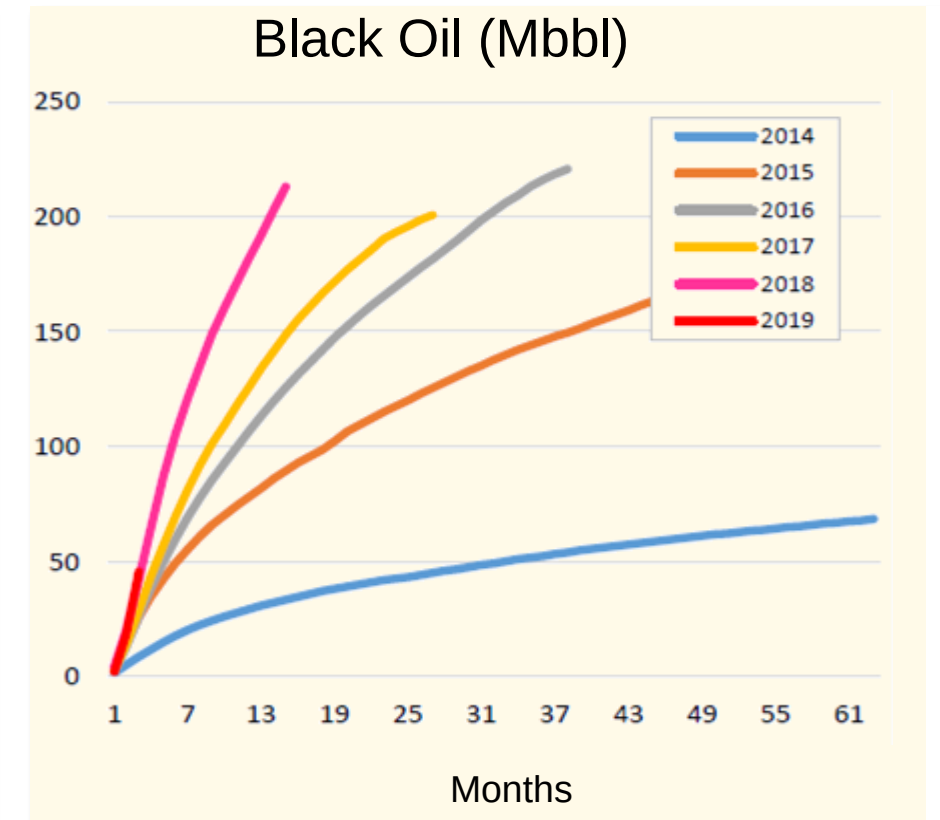
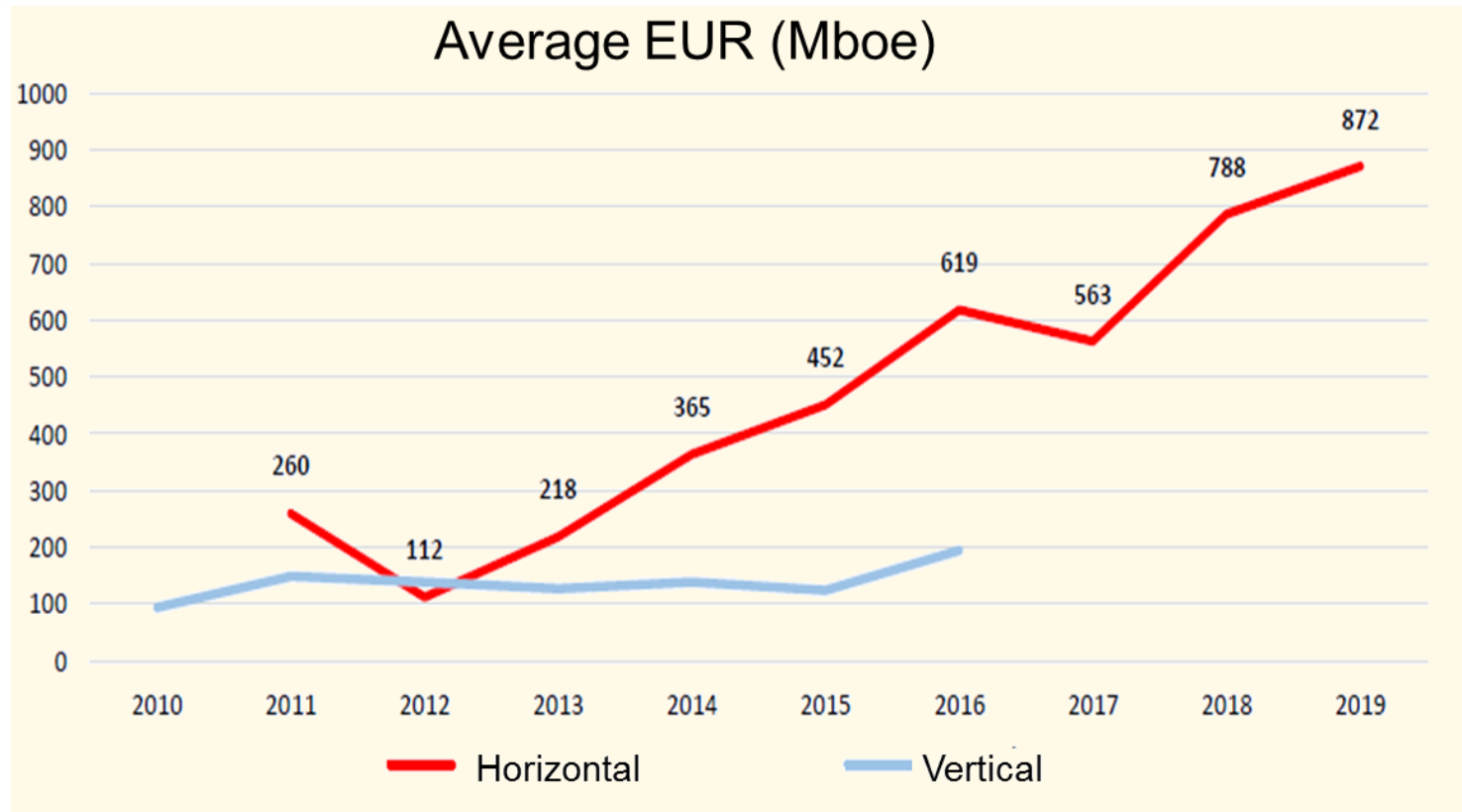


Main Landing Zones

- ★ B4x
- ★ B1x
- ★ Organico (T6.5x)
- ★ Cocina

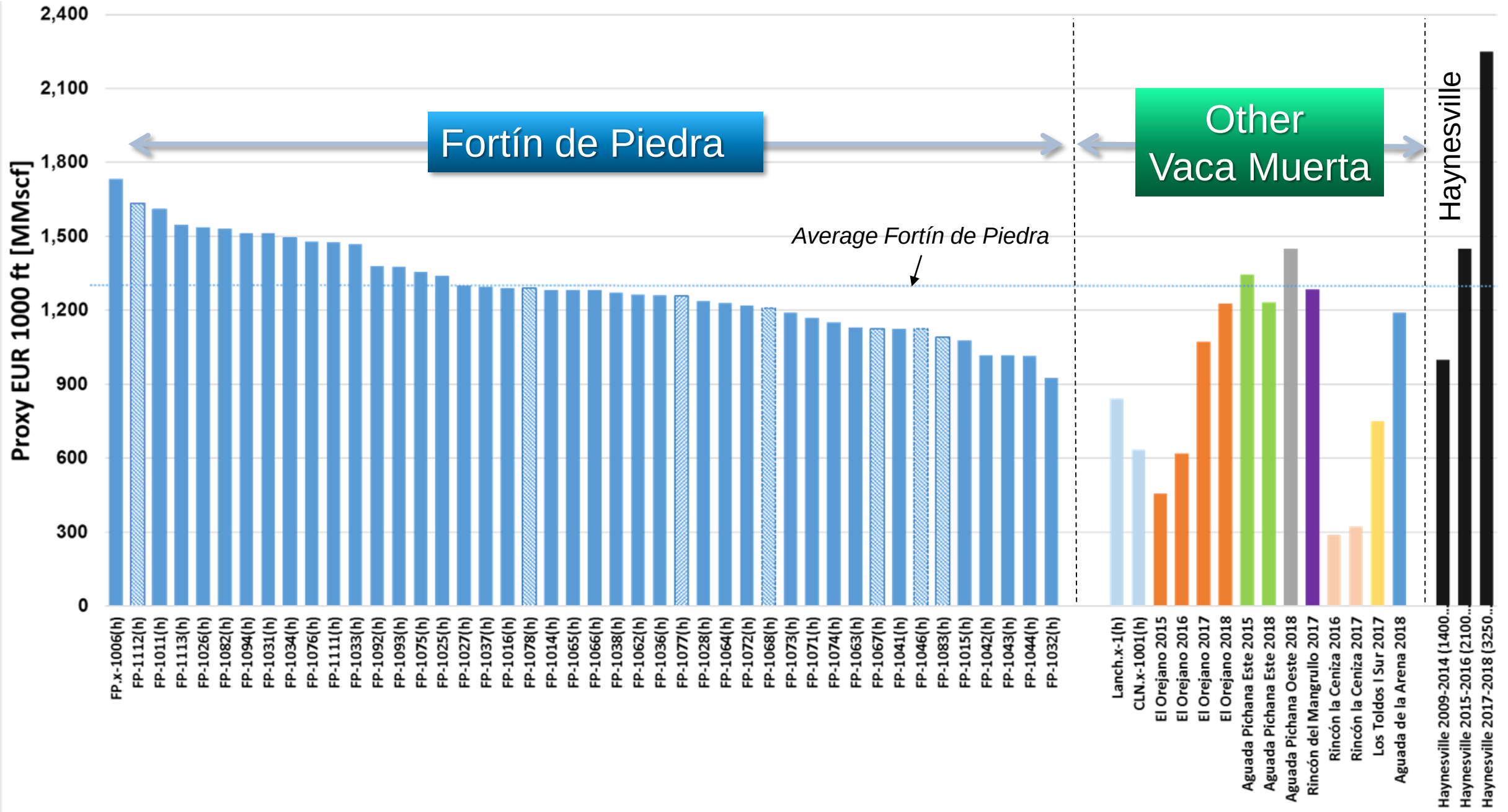


Change in production Vaca Muerta wells

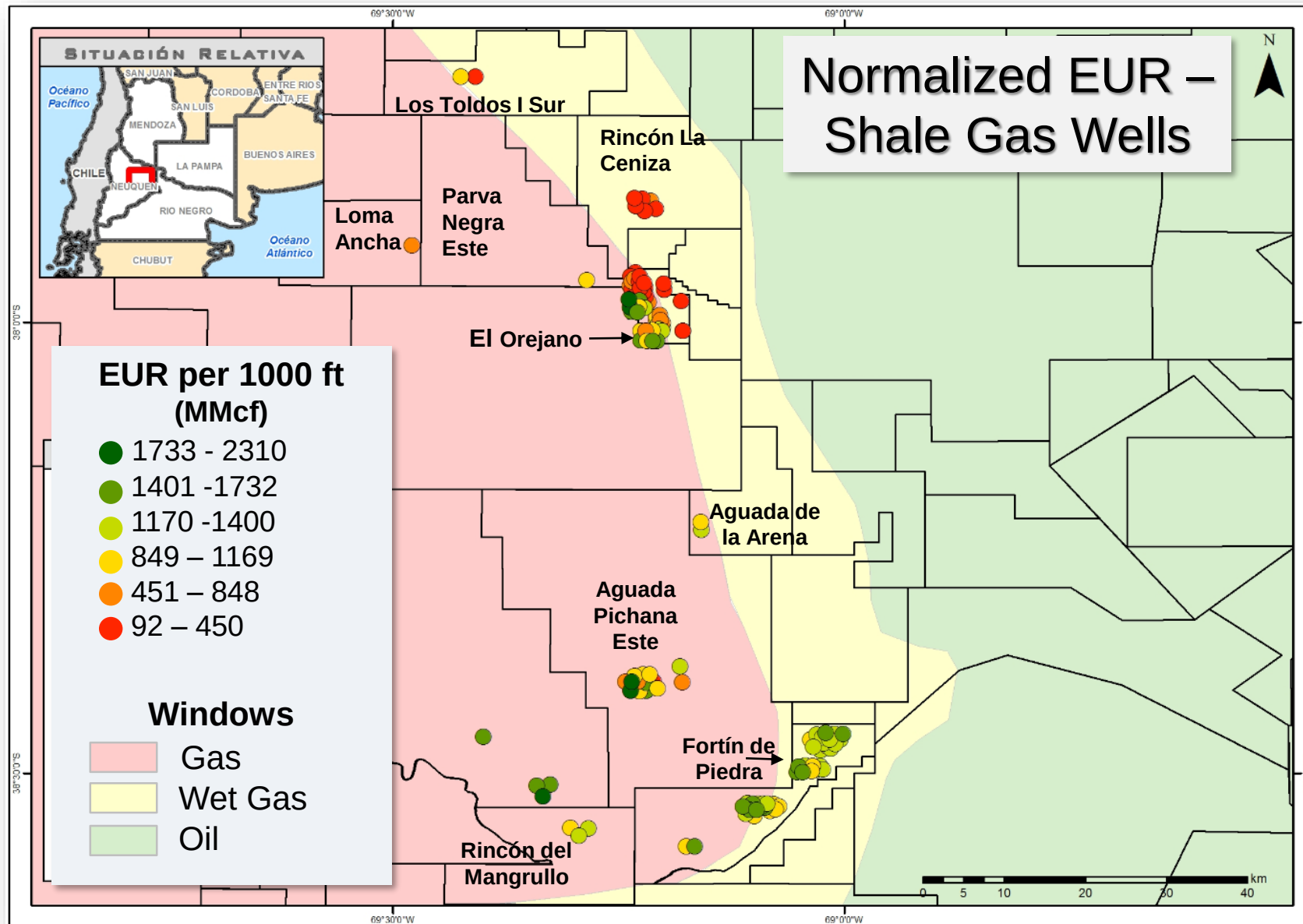


From GiGa Consulting, 2019

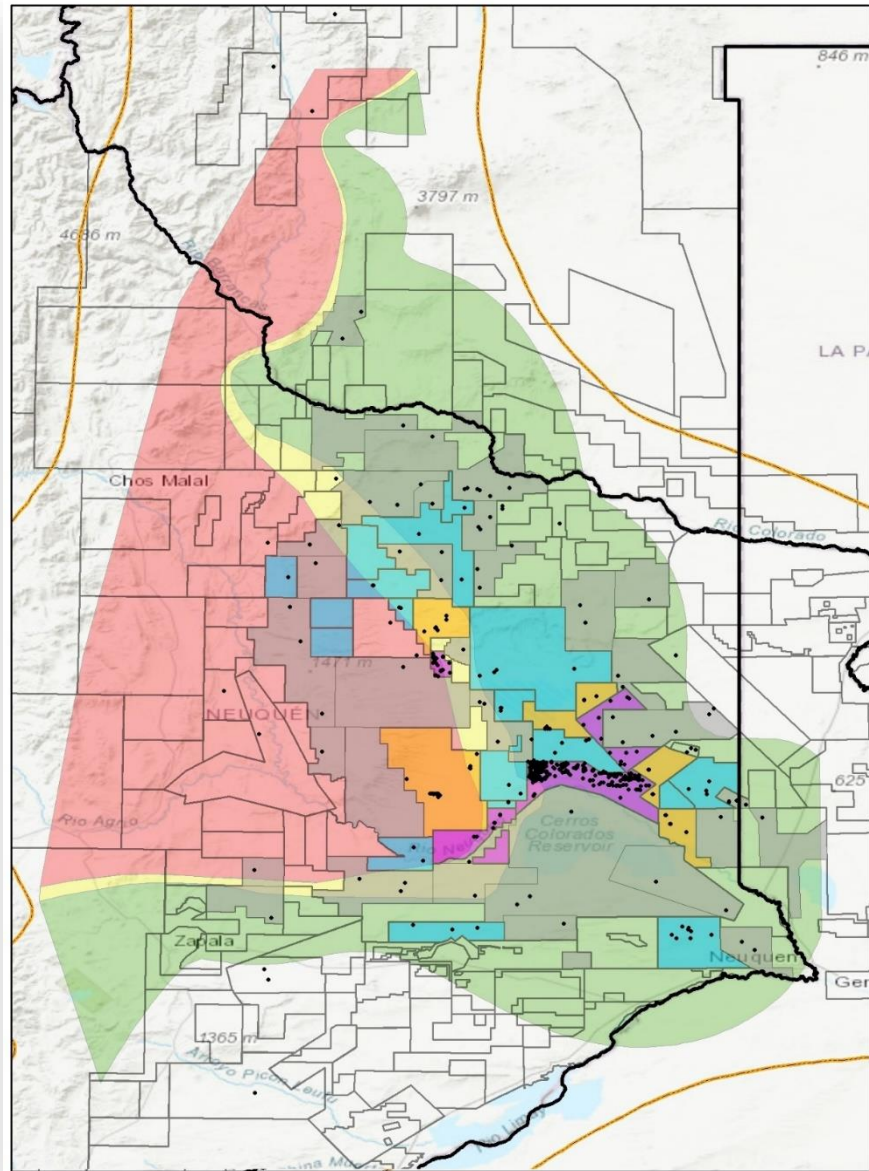
Normalized EUR – Shale Gas Wells



Early Regional Trends in Vaca Muerta



Projects in Vaca Muerta



- Full development
- Pilots
- Recent activity
- Older VM wells

Aproximately 1000 wells drilled to date

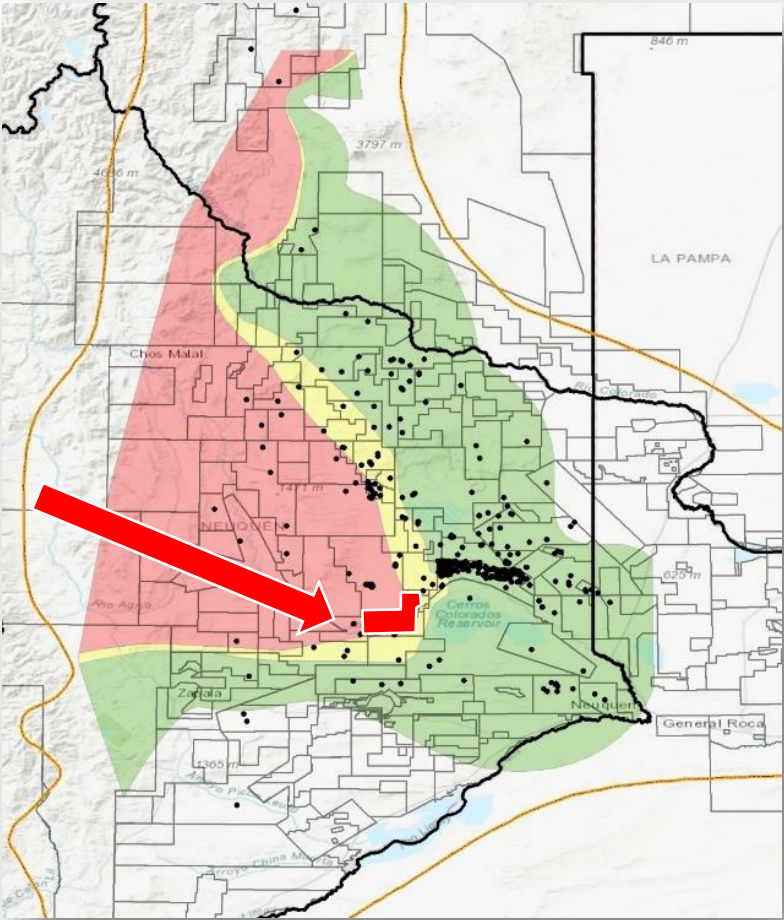
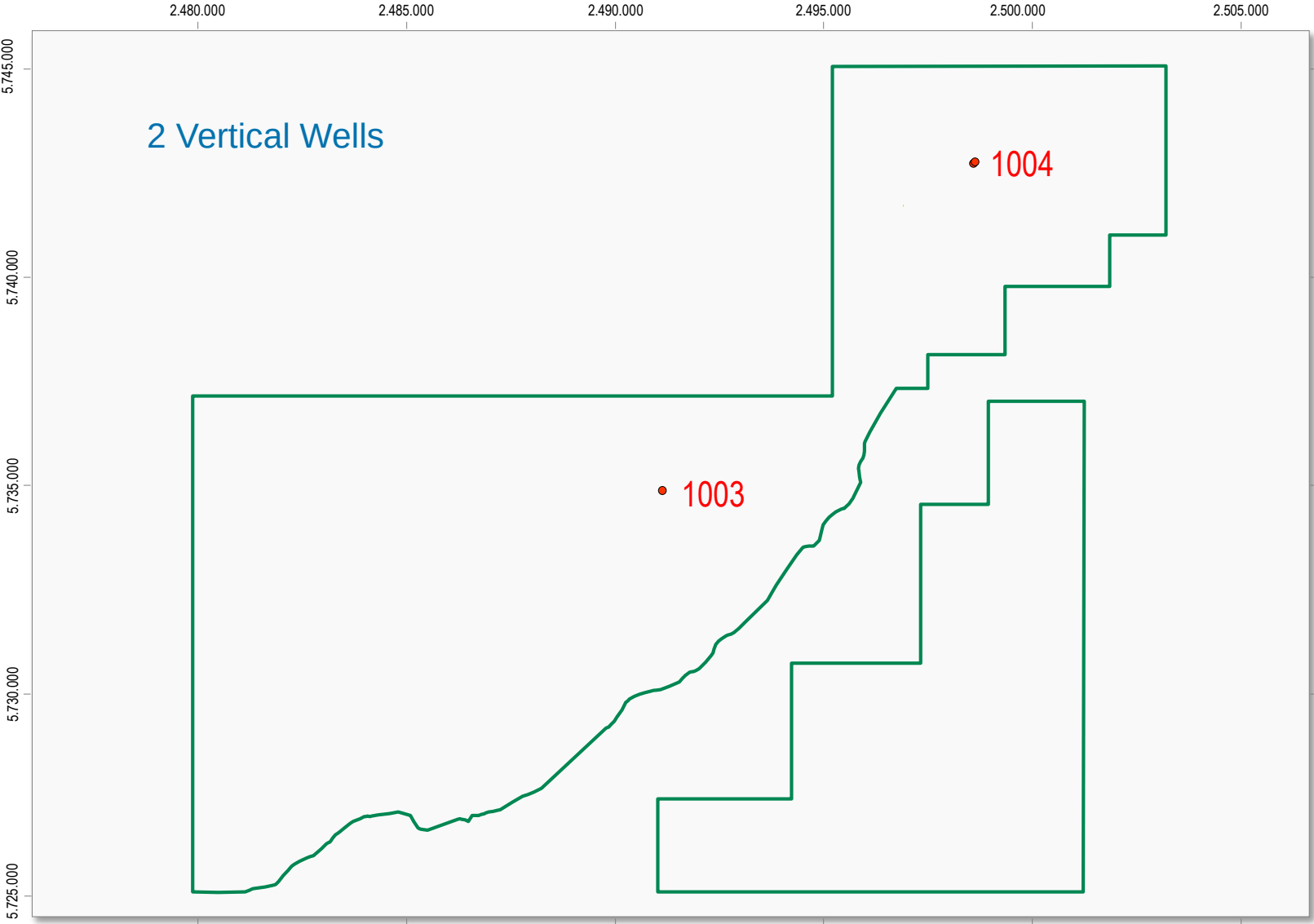
Evolution of Vaca Muerta





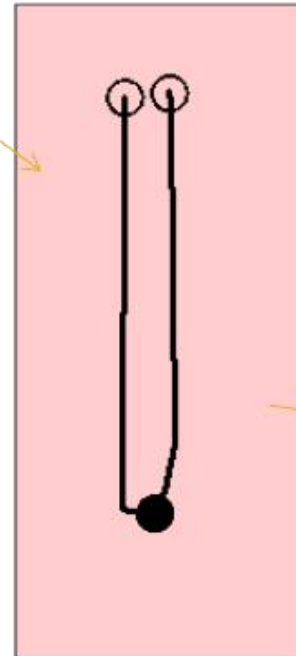
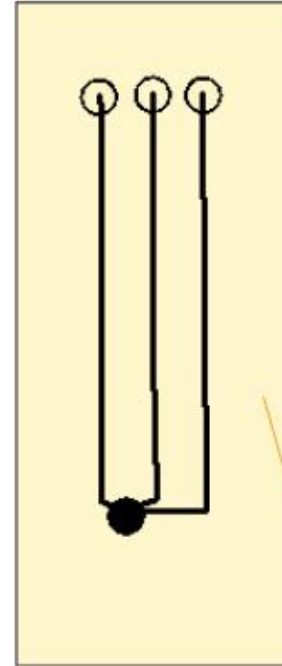
Factory Mode Development Fortín de Piedra

Fortín de Piedra - 2016



Fortín de Piedra - 2017

Appraisal: Drilling of 5 Hz Wells



Hz Wells 1500 m

20 Stages:

Sand: ~5000 sks

Fluid: 1500 m³

Q: ~60 BPM

Max Concentration: 4.5 ppg

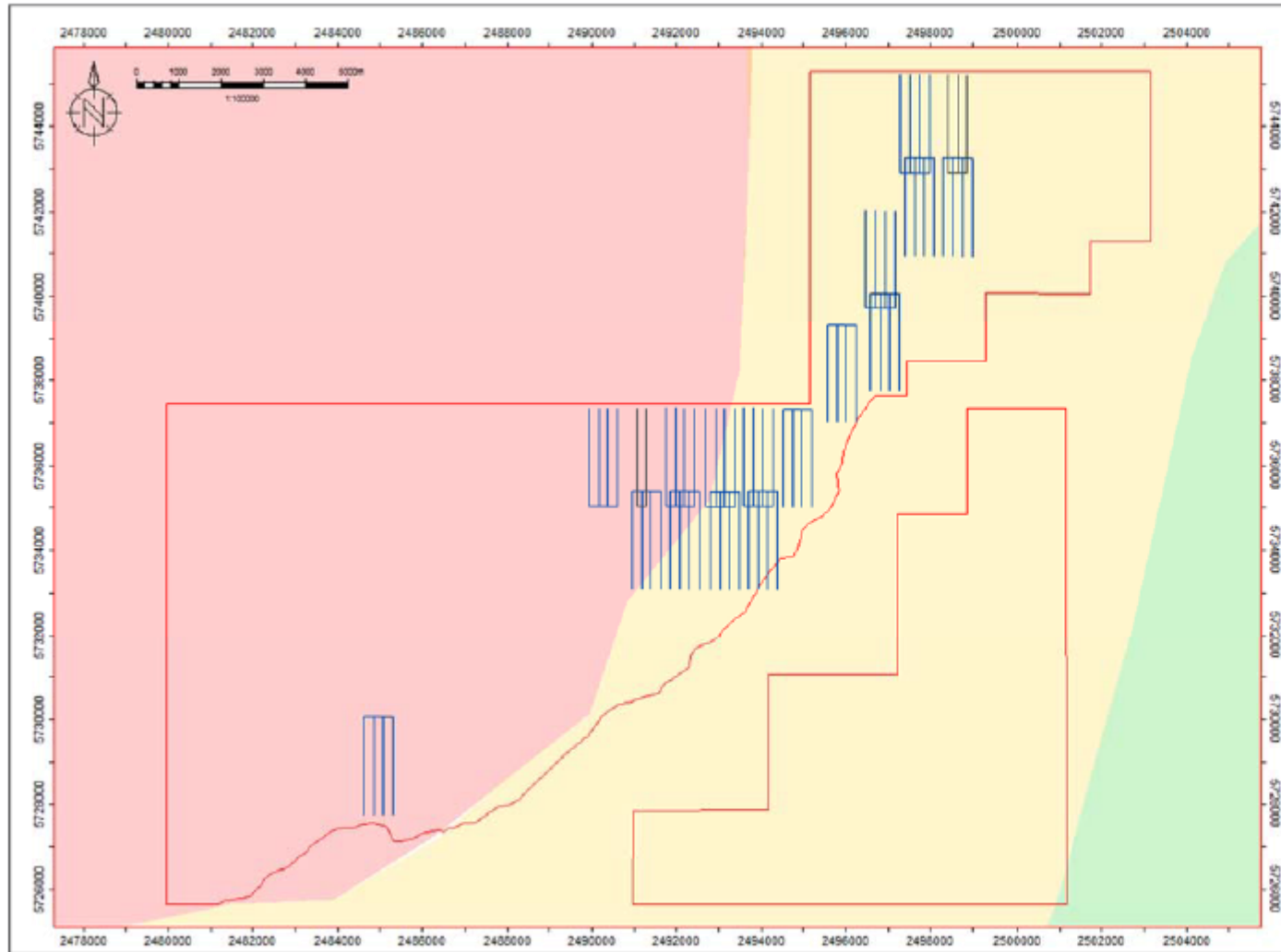
100% Ceramic

2100 pounds ss/foot



Fortín de Piedra - 2018

Accelerated Development (1st Year)



Development Plan:

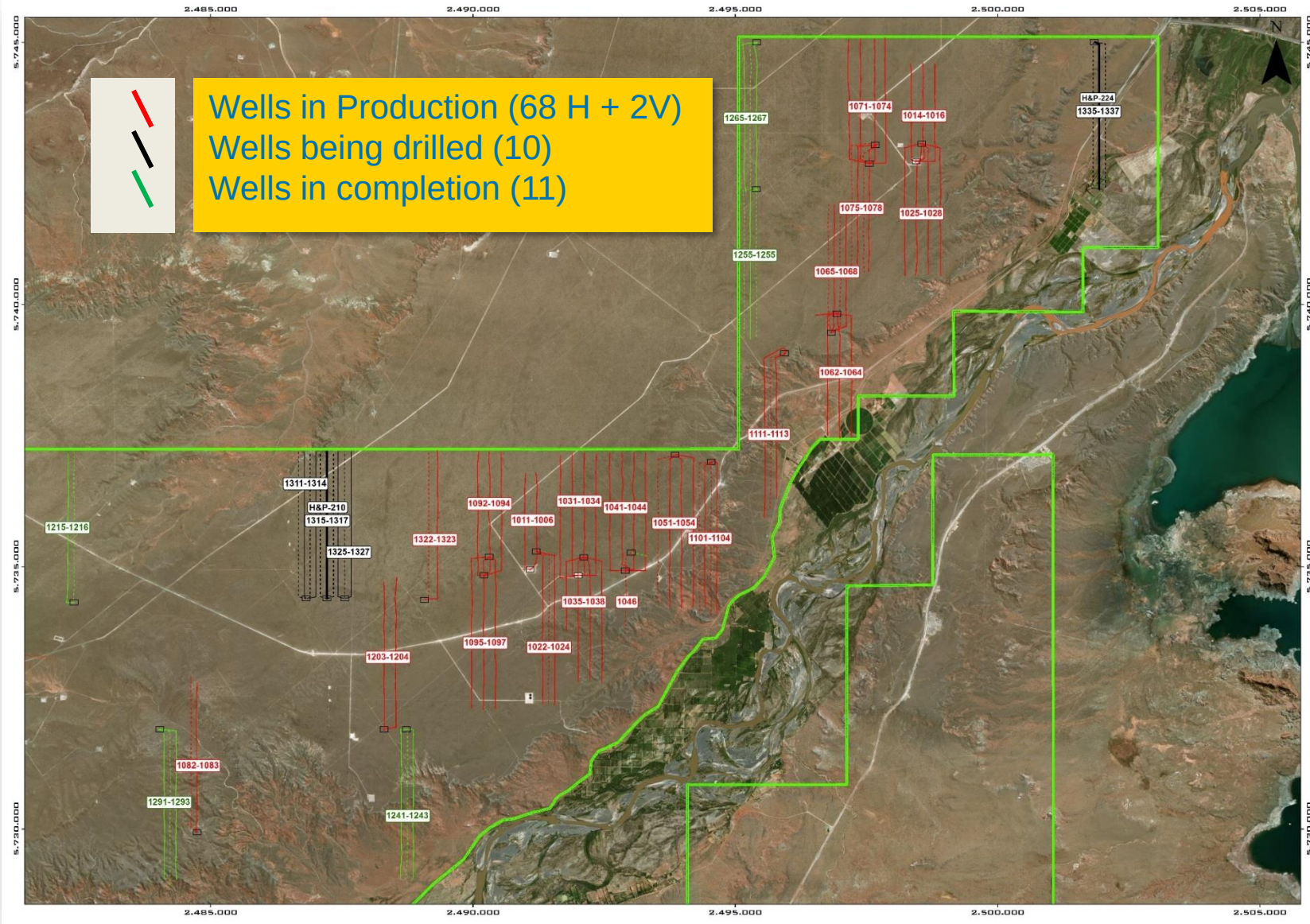
Start: May 2017

6 Drilling Rigs

2 Completion Sets

60 Wells 2000 m lateral

Fortín de Piedra – May 2019



Wells

- 2500 m lateral length
- 63 frac stages (40m)
- 1500 m³ water
- 3800 pounds/feet sand
- All brown ss

Fortín de Piedra – Infrastructure

CPF Plant (Dew Point Plant)



EPF (Early Production Dehydration Plant,
6,5MMm3pd)

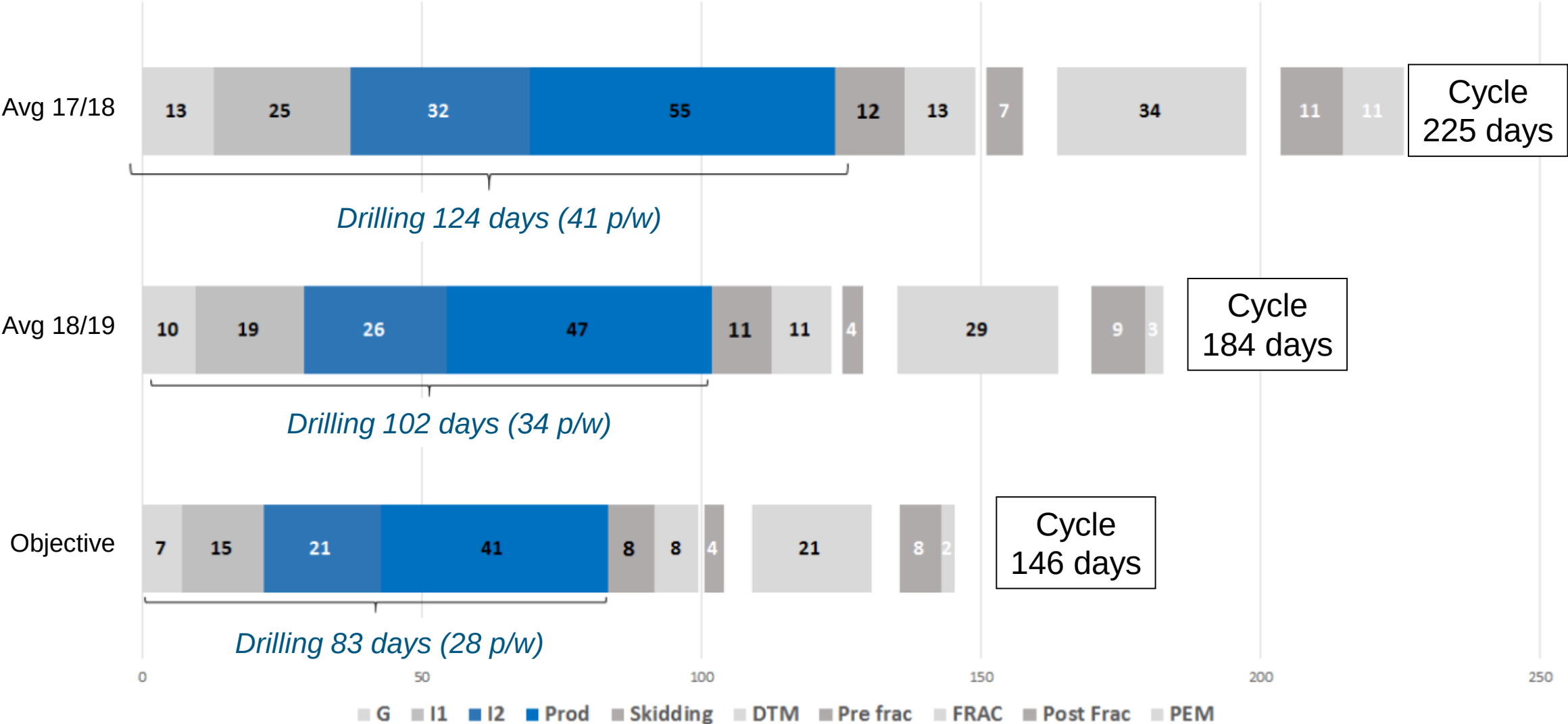


Water Storage and Distribution
System

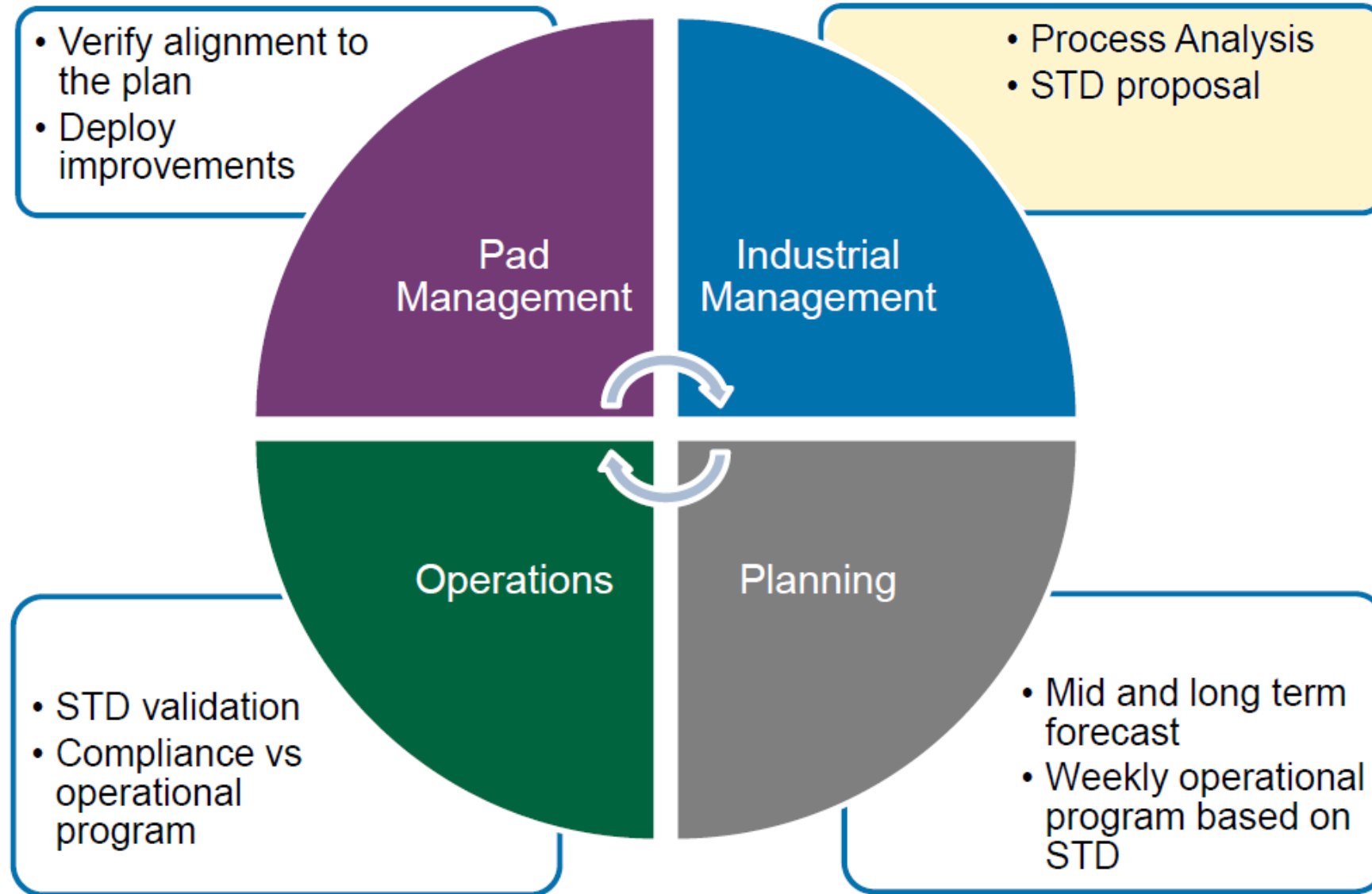


Factory Mode – Process Analysis

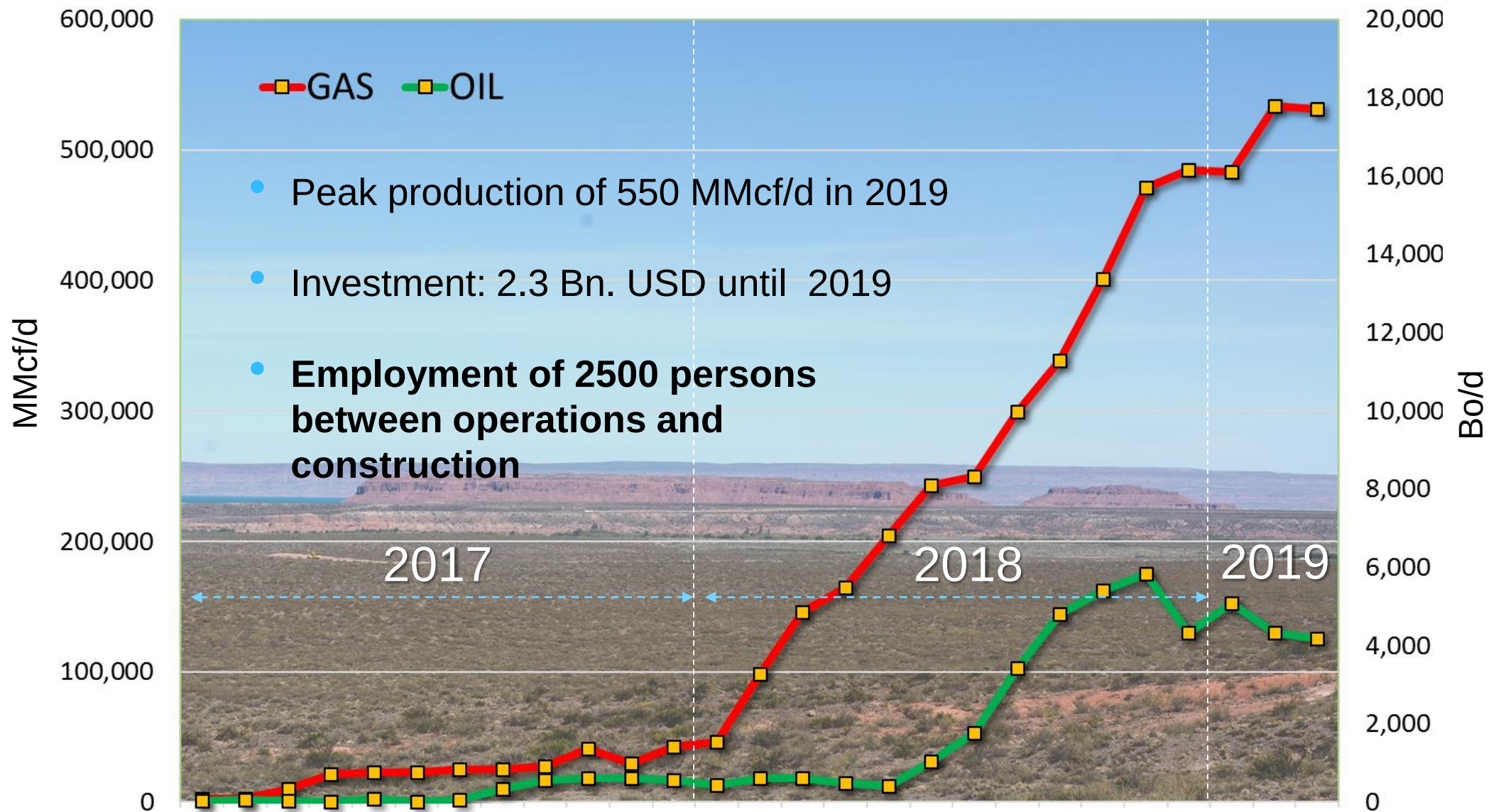
Pad Cycle – 3 wells



Factory Mode – Process Analysis



Fortín de Piedra Block



Conclusions

- Regional studies identified Vaca Muerta as the most prospective unit in Argentina for unconventional development
- Early evidence of Vaca Muerta as potential reservoir in fractured rocks
- Pioneer work of YPF in establishing Vaca Muerta as an unconventional reservoir
- Evolution from vertical to horizontal wells, increase in lateral length, number of fractures, and landing zones.
- Several pilot projects showed encouragement in the play
- The true potential of Vaca Muerta became apparent with the projects that entered in Full Development, particularly with the fast track development, which is now changing the energy spectrum of Argentina.

Acknowledgements

- Tomas Garcia Blanco (Repsol)
- Ivan Lanuse (YPF)
- German Botessi (Vista)
- Hector A. Leanza (CONICET)