Exploration and Development Strategies for Sub-Andean Tight Rock Reservoirs of the Siluro-Devonian, Chaco Plain, Bolivia*

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Abstract

Bolivia has traditionally produced gas from several large naturally fractured gas fields in the Sub-Andean fold thrust belt, many of which have reached peak production and are today in decline. To ensure reserve replacement and the long-term future of the country's major export industry, new sources will be required over the coming decades. Such supply may exist in thick laterally continuous Siluro-Devonian tight gas sandstones of the Los Monos-Huamampampa and Icla-Santa Rosa-Kirusillas Formations that underlie the vast Chaco Plain. Typical of 'basin-wide' petroleum systems, the in-situ resource potential of the Chaco is likely to exceed several hundred TCF and to be of national significance. However, exploration and development of this resource will require a new approach for Bolivia, where project execution is driven by the drilling and completion of 100s of wells on a manufacturing scale. Although such a development may appear initially challenging, similar resources are being rapidly developed in many parts of the world, due in large part to advances in horizontal drilling, hydraulic fracturing, super-pad development, and gains in operating efficiency. With a backdrop of increasing competition and plentiful global gas supply, we will discuss what it will take to build a successful Bolivian economic ecosystem around a tight gas extraction industry.

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Geosciences Technology Workshop

Exploration and Development Strategies for Sub-Andean Tight Rock Reservoirs of the Siluro-Devonian, Chaco Plain, Bolivia

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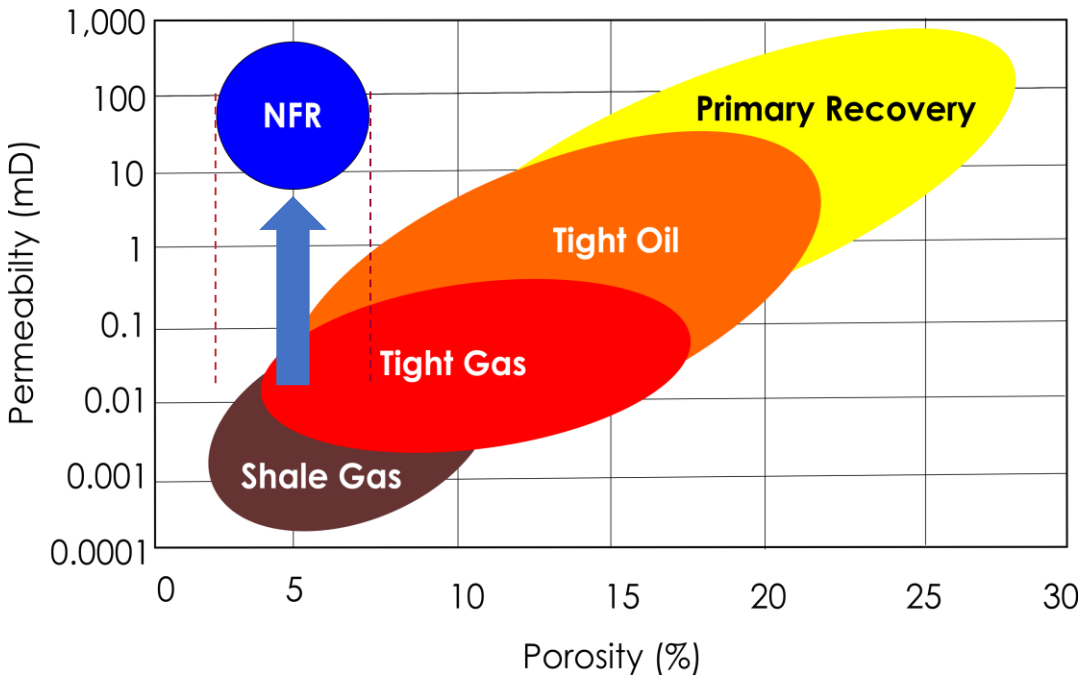
Outline

- Tight Rock Reservoirs
- Chaco Plain – The Exploration Concept
- Chaco Tight Gas Petroleum System and Resource Distribution
- Analogues
  - Depositional – Cotton Valley / Bossier / Haynesville
  - Scale – Montney / Duvernay, Canada
  - Development – High Plains DJ Basin
- The hard work has been done !
- Well Economics – 50/50 (The Paradigm Shift)
- How many wells needed to double current Bolivian reserves and maintain production?
- The Opportunity

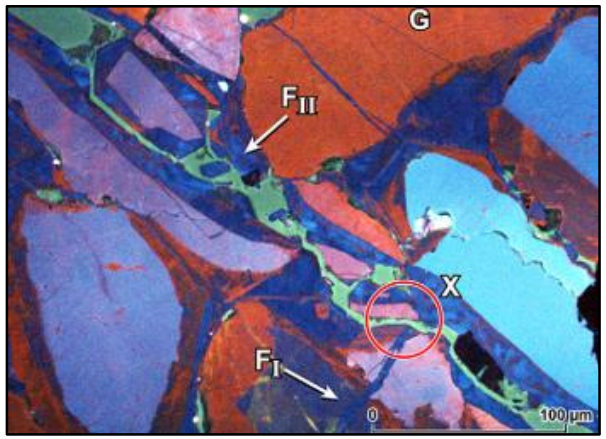
DISCLAIMER: Today there is abundant publicly available information on low permeability tight rock reservoirs with many world class geoscientists and engineers working daily in the space. This short presentation taken from personal and public data sets will likely do many of them an injustice, for which I apologize in advance. All public data used in this ppt is referenced at the end of this presentation.

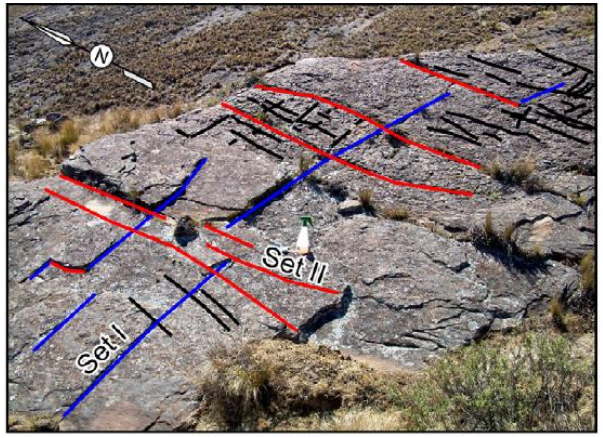
Tight Rock Reservoirs



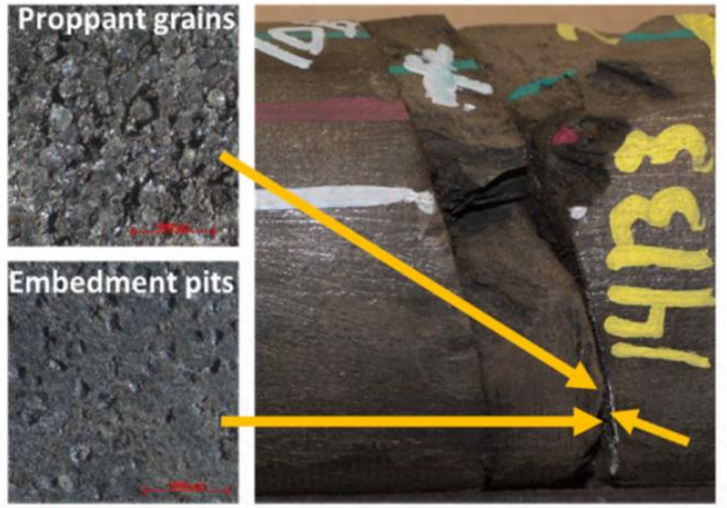
- Prolific fields in the Sub-Andean zone (e.g. Margarita, 13 TCF) produce from naturally fractured Devonian sandstones
- Most "conventional" reservoirs in Bolivia have inherently low matrix poro-perm "Tight Rock" characteristics (they are just naturally fractured - NFR)
- Prolific production rates in the Bolivian thrust belt reflect extensive extensional and "self-propping" discrete fracture networks associated with regional tectonism
- Thick and brittle Devonian sandstones in anticlinal hinges and flower structures, when coupled with conjugate high deliverability fractures, results in exceptional EURs
- Hydraulic fracturing of Tight Gas Sands is industry's way of replicating mother nature's natural fractures. My simple way of thinking: we are changing r_w

$$p = p_{wf} + \frac{141.2 q_o \mu_o B_o}{kh} \ln(r/r_w)$$





Core from Eagle Ford SRV Pilot Horizontal Sampling Well



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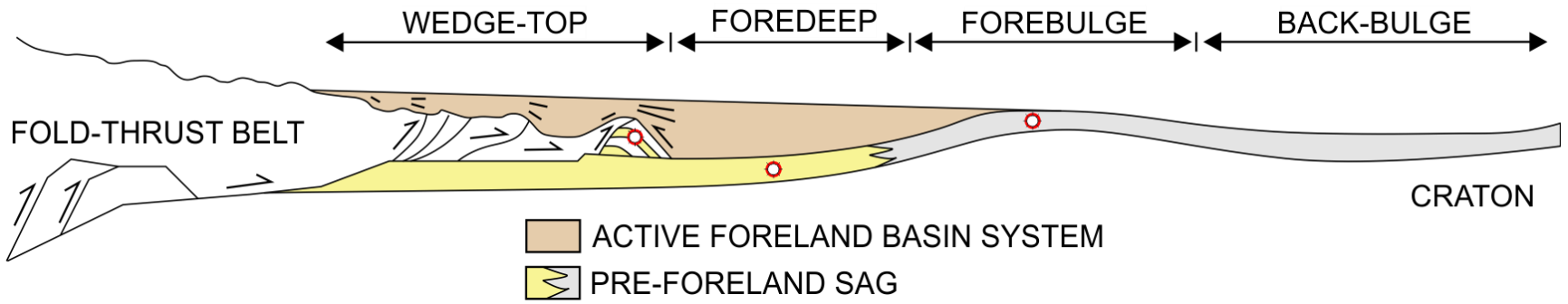
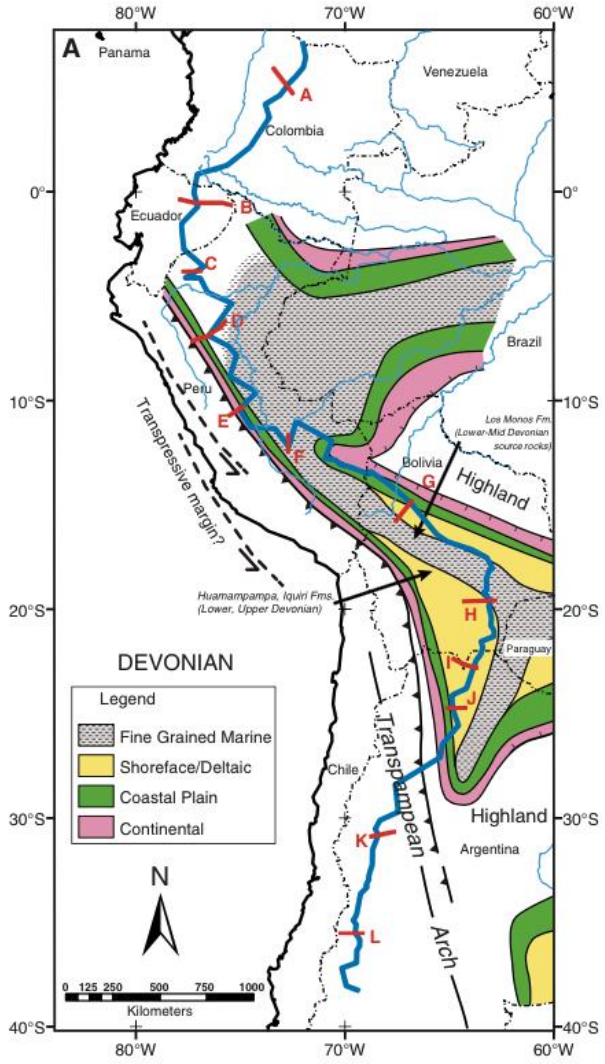
Tight Rock Reservoirs – what they look like !

Natural Gas Desorbing from Tight Rock Core (Depth 5,336 ft)

Chaco Plain – The Exploration Concept

- The Chaco Plain could contain one of South America's largest continuous Tight Gas accumulations
- Key exploration target lies in the thick undeformed Siluro-Devonian 'pre-foreland basin sag'
- Devonian fill of the Chaco Basin comprises shallow marine, shore-face and deltaic sands along the SW and NE basin margins
- Key tight reservoir targets are the basinal facies of the prograding clastic margins, where sandstones and source rocks are interbedded in the Iquiri, Los Monos, Huamampampa, Icla and Santa Rosa Formations
- The low topographic relief of the Chaco Plain and proximity to pipeline and export infrastructure will facilitate rapid resource play development





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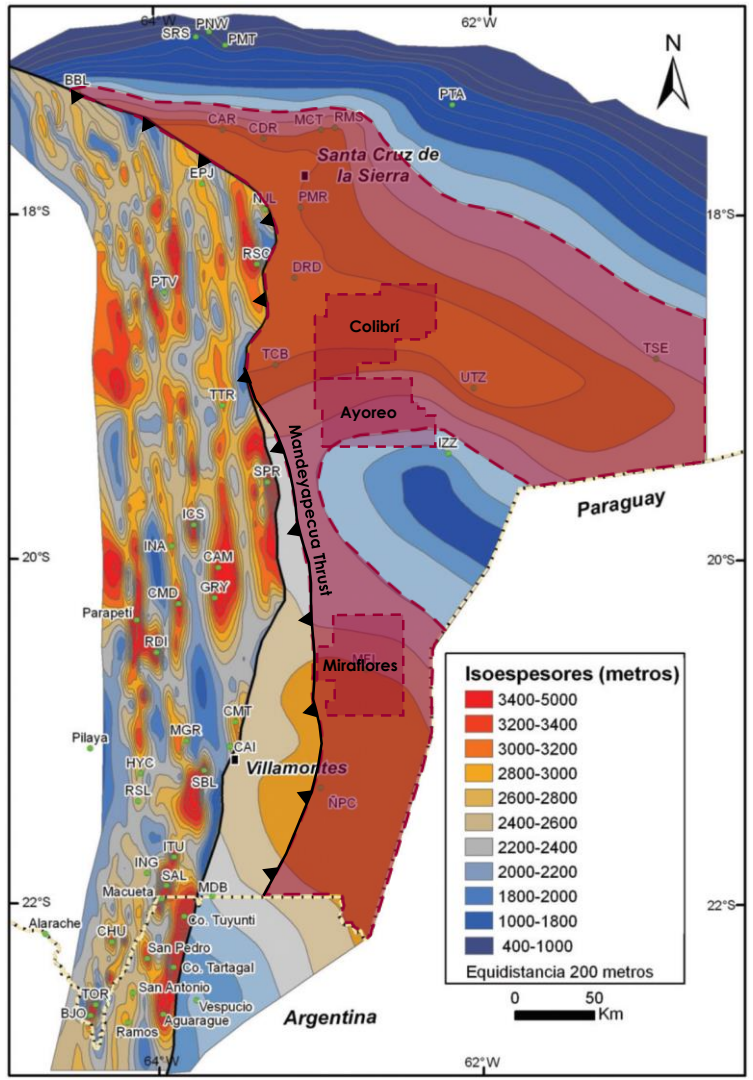
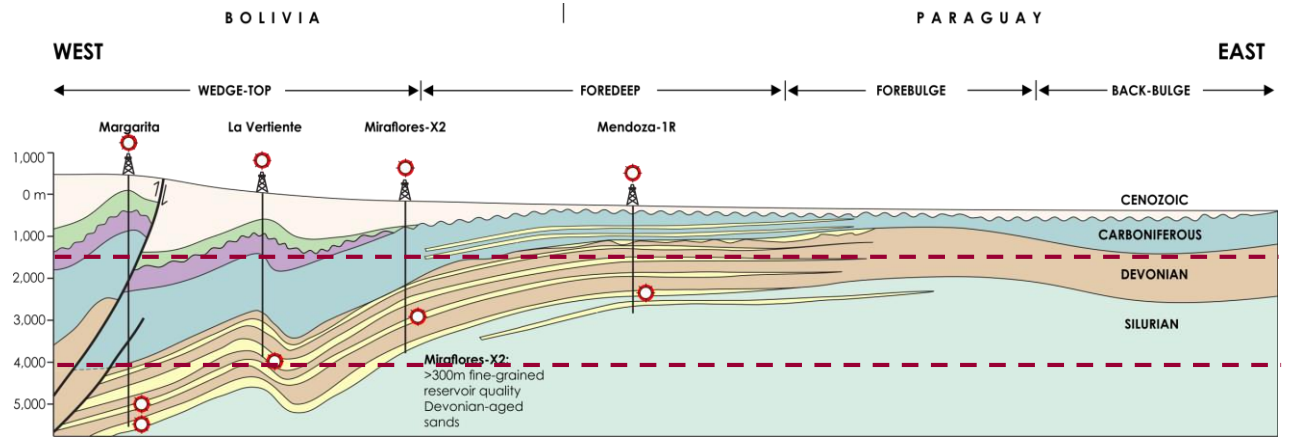
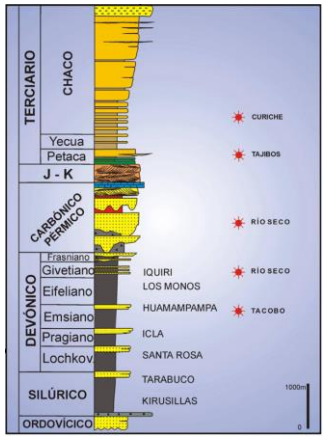
Chaco Tight Gas Petroleum System & Resource Distribution



- There are currently no commercial Siluro-Devonian discoveries in the Chaco foredeep. Low-permeability gas bearing sequences, previously considered non-reservoir will be completed as tight gas reservoirs (proven in Miraflores-X2 and Mendoza-1R)
- The forebulge brings the Silurian and Devonian rocks to depths (1.5-4 km) suitable for HZ drilling and multiple fracture completions
- Stacked laterally continuous sandstones cover 1,000s of sq kms
- Regional continuity and thickness of the Siluro-Devonian over 20,000,000 acres suggests a very large OGIP
- Using conservative back of the envelope calculations the OGIP in the Devonian alone is estimated at >850 TCF
- Underlying Silurian section likely contains an additional >300m of tight reservoir pay



Schematic cross section through Chaco Foreland Basin



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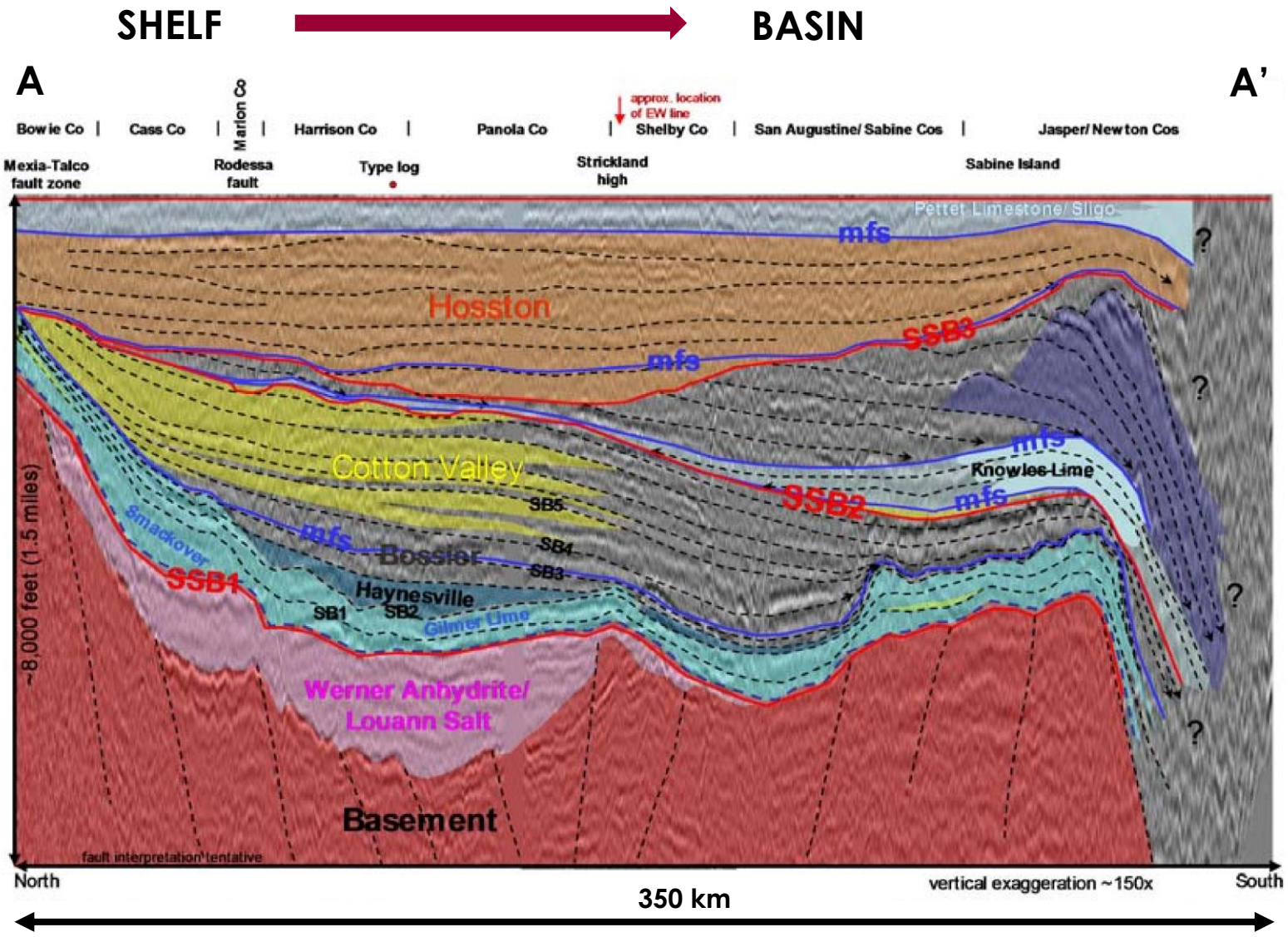
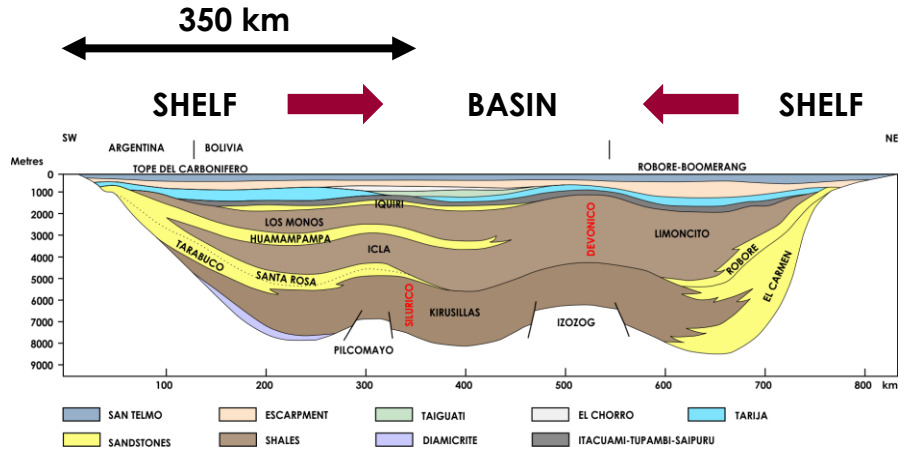
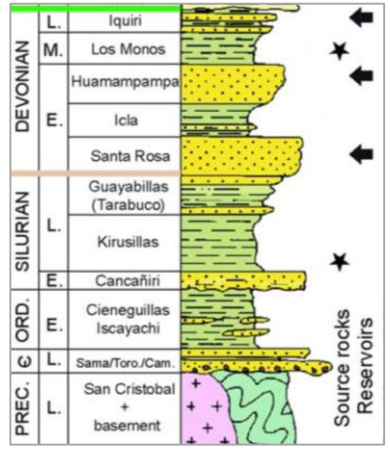
Depositional Analogue : Cotton Valley-Bossier-Haynesville





One of North America's largest tight gas provinces, the Cotton Valley Sands-Bossier-Haynesville Shale, is a shelf-basin transition similar in character to the Chaco Basin fill



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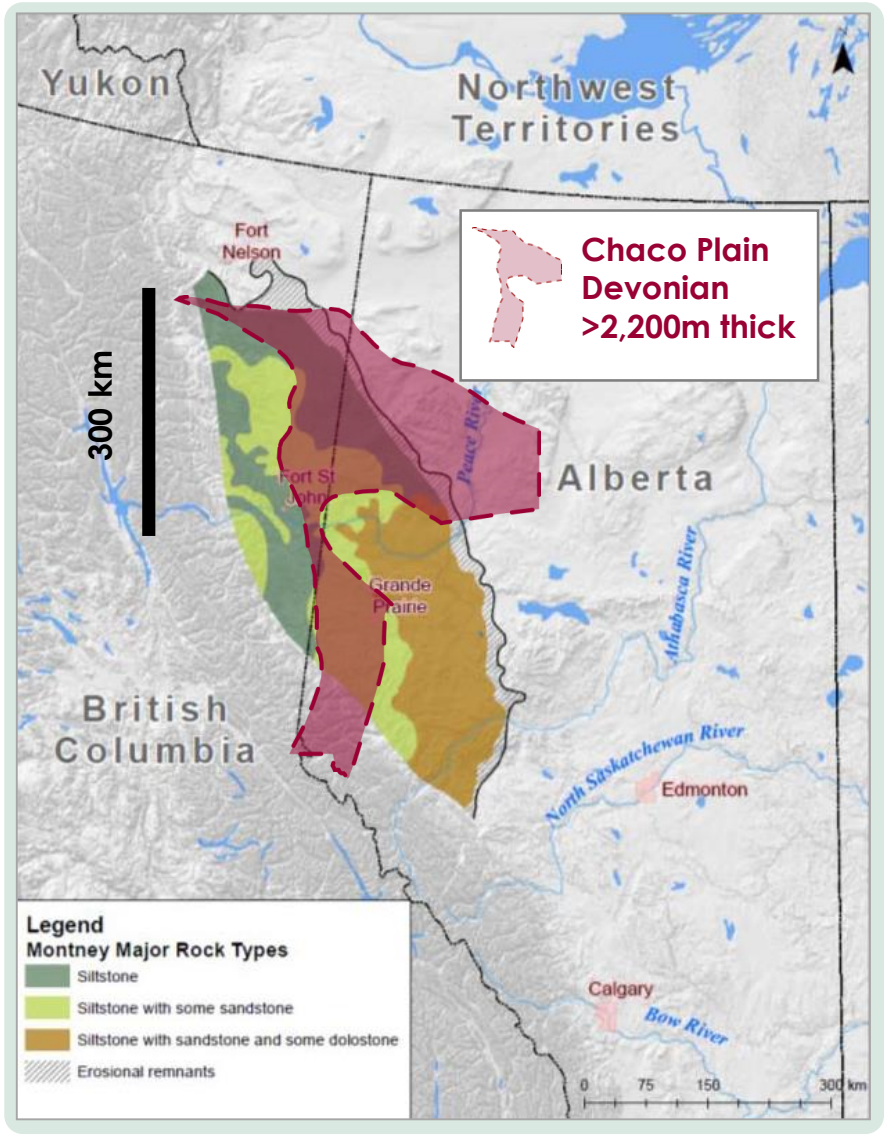
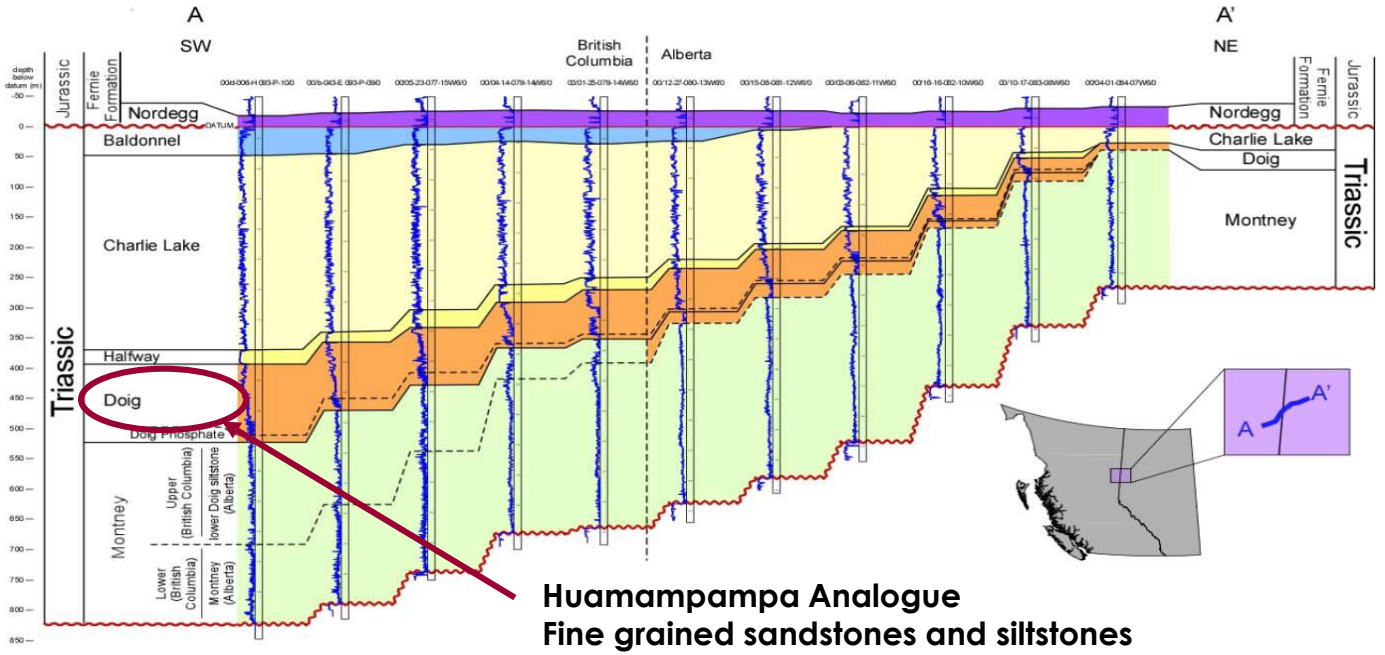
Scale Analogue : Montney-Duvernay, Rockies



Hydrocarbon Type	In-Place (from ERCB/AER Reports)			Marketable (this report)		
	Low	Expected	High	Low	Expected	High
Natural Gas – billion m^3	48,124	**65,415**	83,474	3,286	**5,042**	7,946
(trillion cubic feet)	(1,699)	**(2,309)**	(2,947)	(116)	**(178)**	(281)
NGLs – million m^3	1,910	**4,863**	8,924	122	**298**	584
(million barrels)	(12,020)	**(30,599)**	(56,150)	(769)	**(1,874)**	(3,674)
Oil – million m^3	12,654	**22,045**	35,373	71	**174**	375
(million barrels)	(79,621)	**(138,706)**	(222,569)	(444)	**(1,096)**	(2,360)

Ultimate potential for Montney, including lowermost Doig siltstone, Alberta/ BC



Huamampampa Analogue
Fine grained sandstones and siltstones
Poroperm: 5% / 0.01 mD
Thickness: 80-700m

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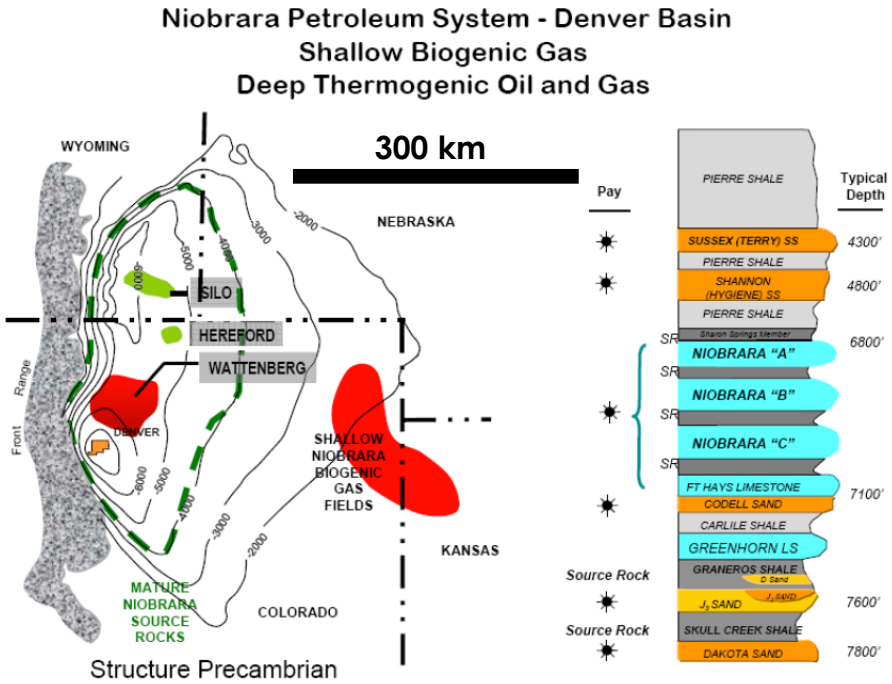
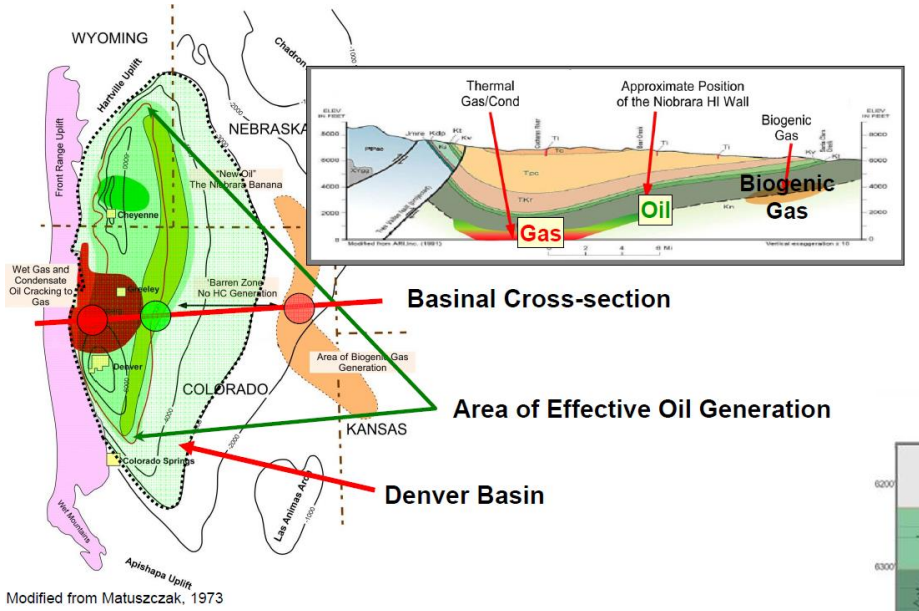
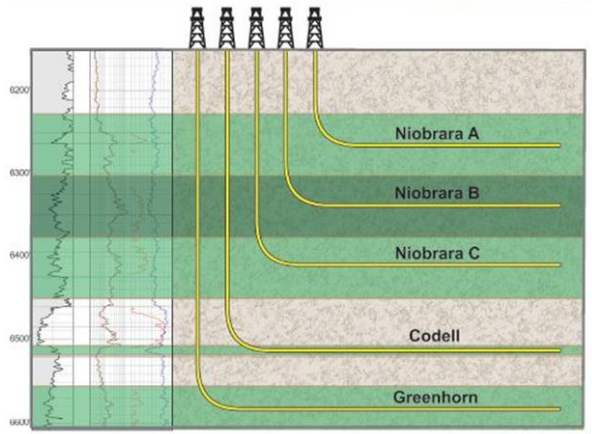
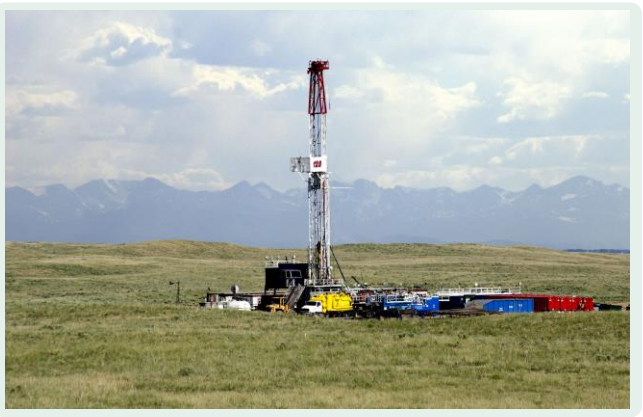
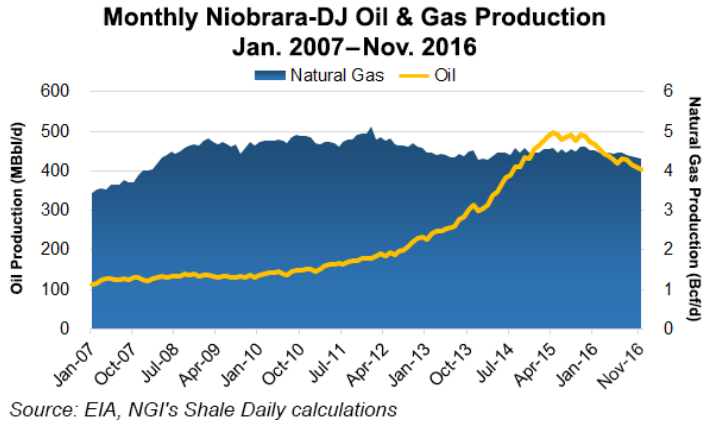
Development Analogue : DJ Basin, Rockies











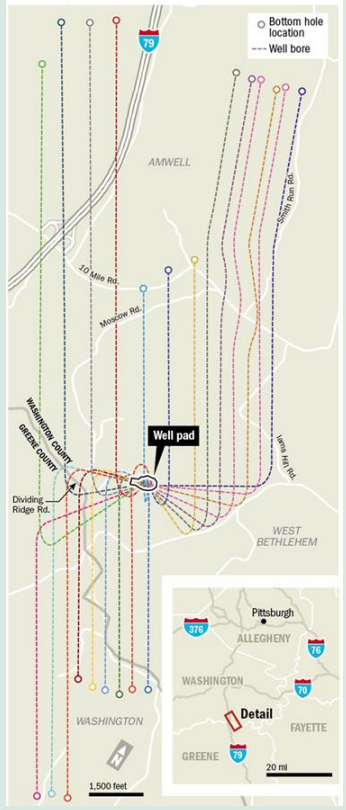
Source: EIA, NGI's Shale Daily calculations

4 Bcf/d = 120 MMcm/d
400K Boe/d

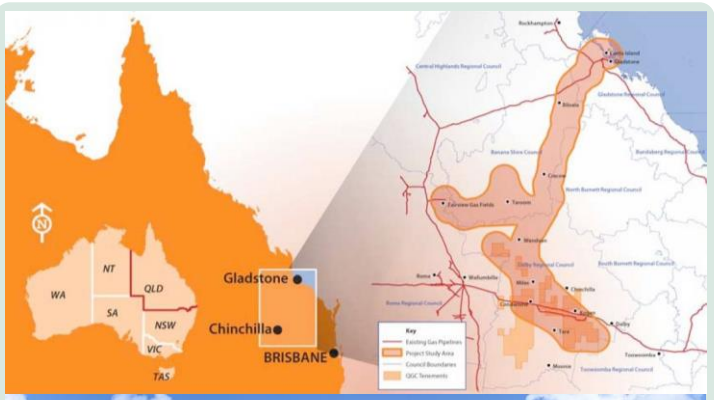
The hard work has been done !

IN BOLIVIA WE ARE NOT STARTING FROM SCRATCH

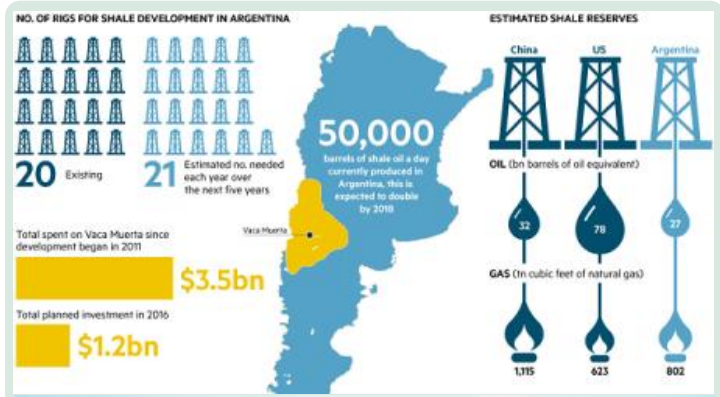
Pennsylvania, U.S.



Australia

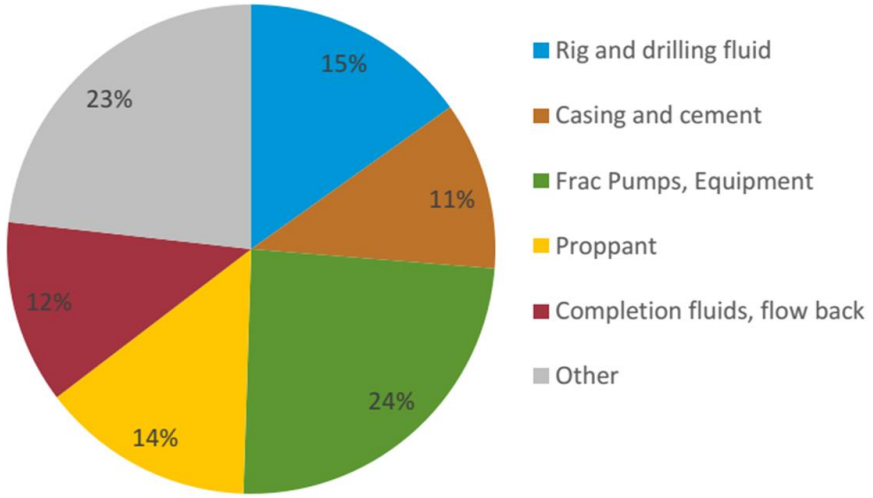


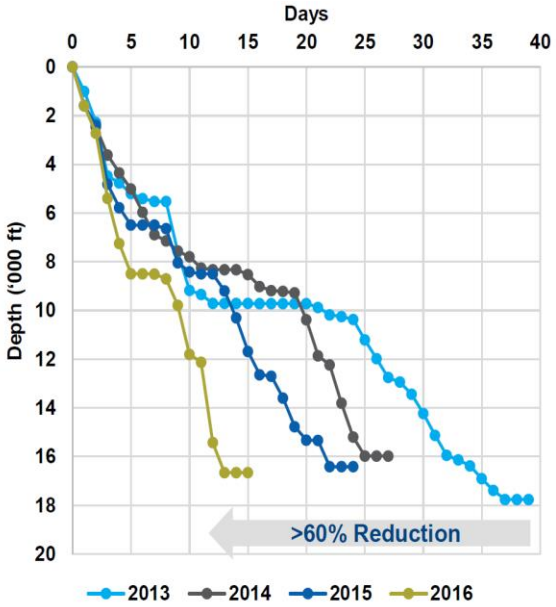
Argentina



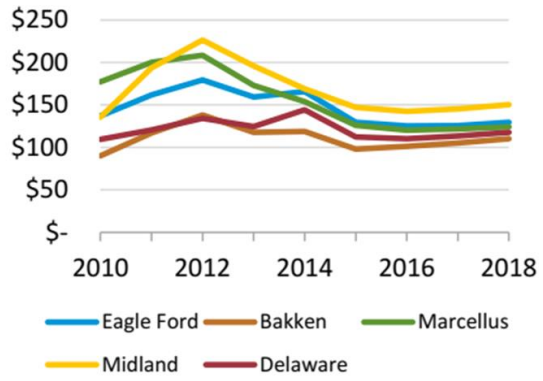
Technology is Transferable

Well Economics – 50/50 (Paradigm Shift)

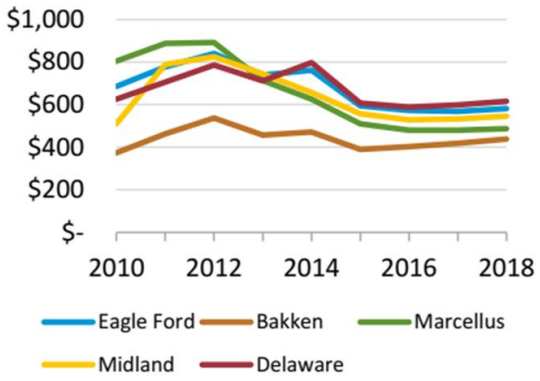




Drilling Cost per Total Depth
$ per foot



Completion Cost per Lateral Foot
$ per foot

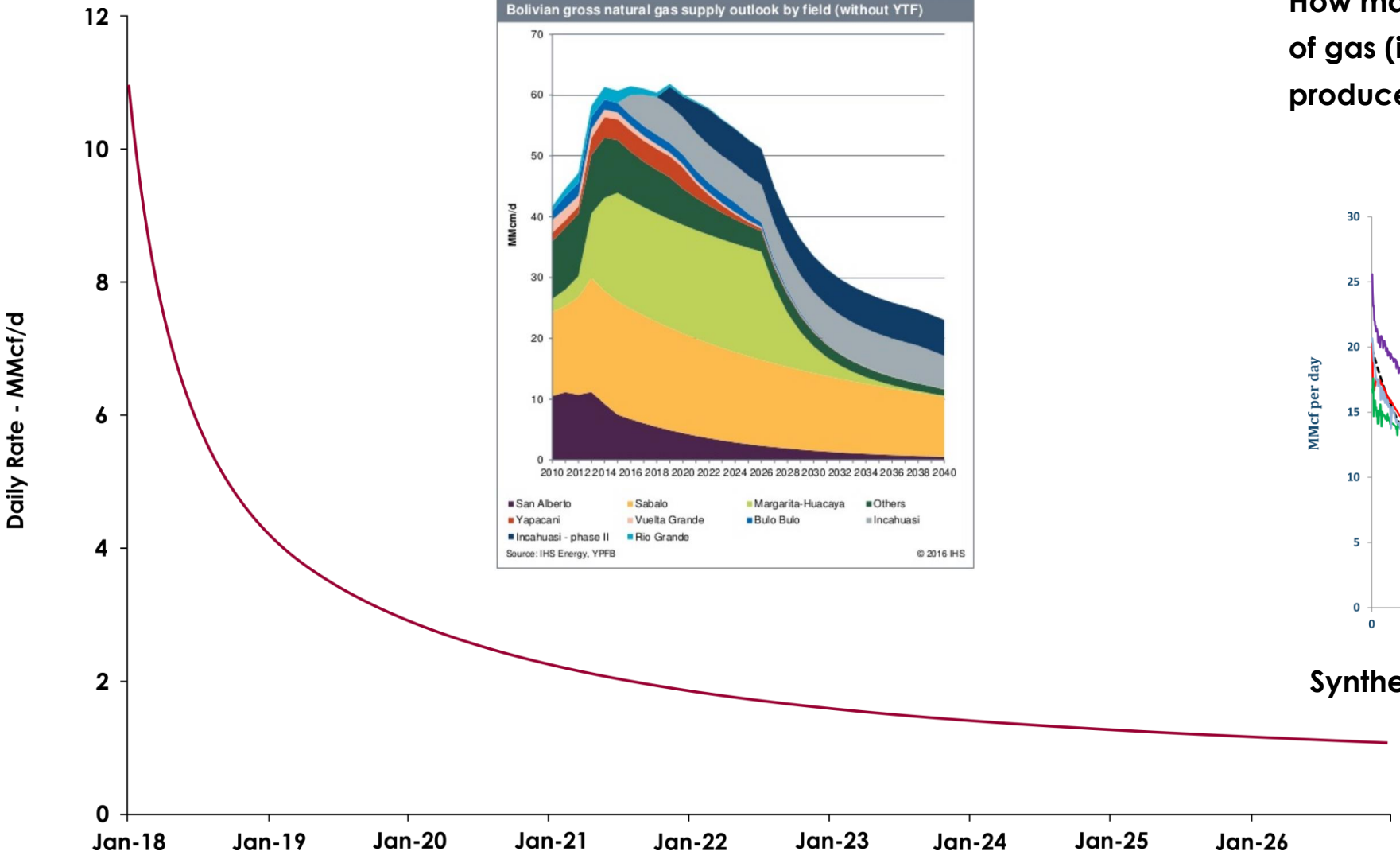


N. Louisiana Economics

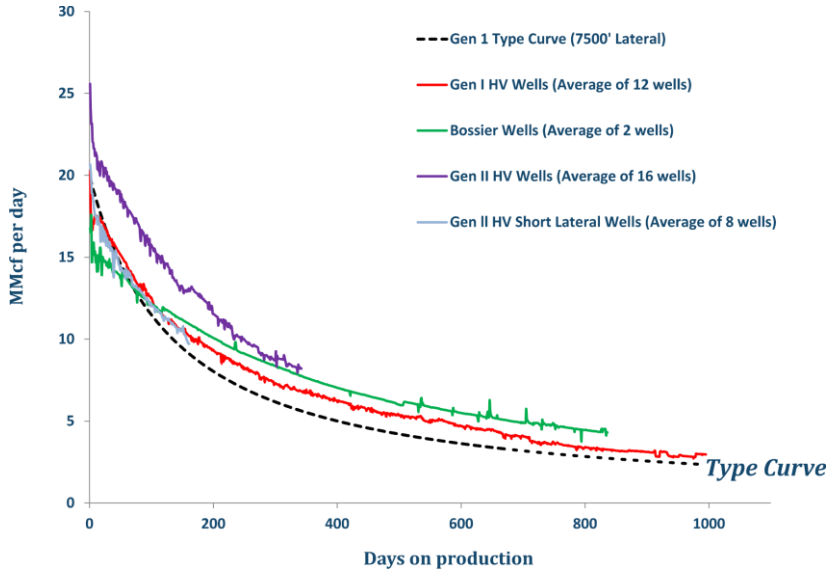
	Combined Lower Cotton Valley
EUR	12.1 Bcfe
EUR/1,000 ft. lateral	1.61Bcfe
Well Cost	$8.4 MM
Cost/1,000 ft. lateral	$1,120 K
Lateral Length	7,500 ft.
IRR* - $3.00	33%
IRR at Strip as of 12/29/17	27%

Complete change in our way of thinking

How many lateral wells needed for 10 TCF / 600 BCF per year ?



How many wells needed to produce 10 TCF of gas (i.e. double 1P proven reserves) and produce at +/- 600 BCF per annum



Synthetic Bossier Analogue Well - EUR 12.1 BCF

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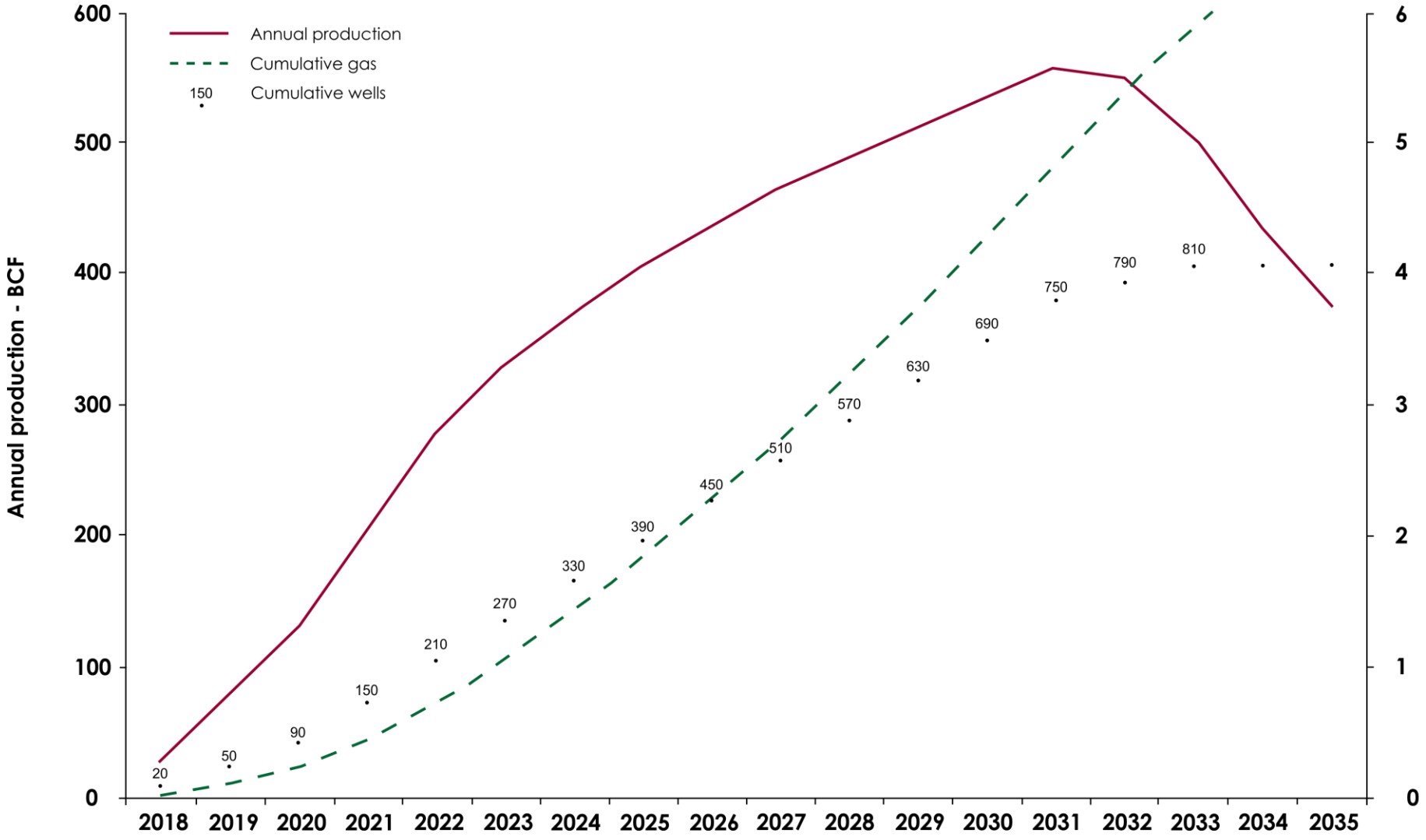
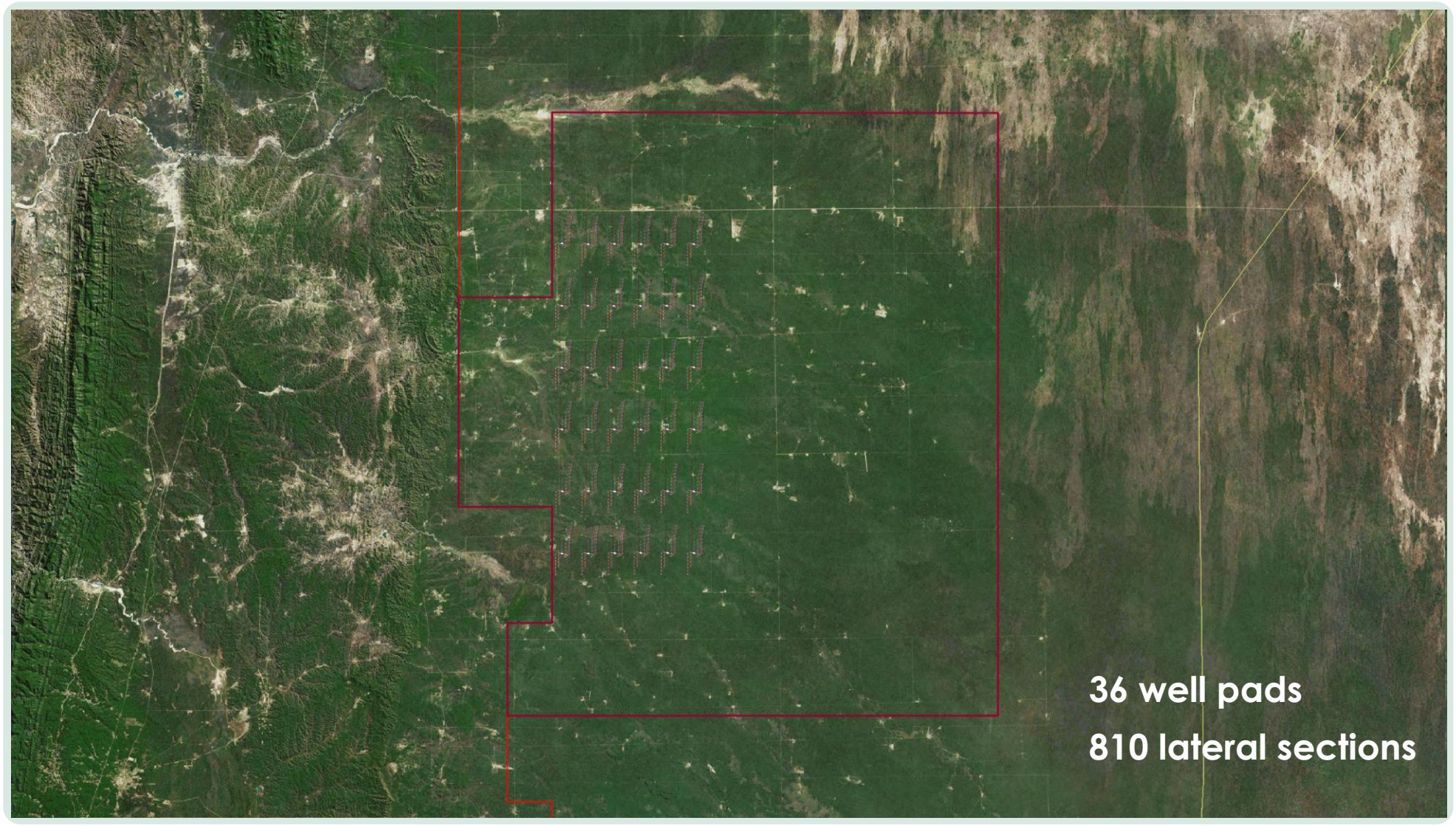
810 Lateral Wells = 10 TCF over 45 years



810 wells over 16 years

Drilling Rate
Year 1 : 20
Year 2 : 30
Year 3 : 40
Year 4-14 : 60
Year 15 : 40
Year 16 : 20

Miraflores - Development Strategy for a World Class Play



Development Drivers – Chaco Plain

TECHNICAL DRIVERS

- Hydrocarbon Generation
- Thickness / OGIP / GOR / Composition
- Pressure Regime, Burial and Maturity
- Gas Chemistry
- Reservoir / Regional Sandstone Distribution
- Inversion / Erosion / *In situ* Tectonic Stress
- Water Saturation / Moveable Water
- Reservoir Compartmentalisation
- Matrix Permeability and TGS Porosity

COMMERCIAL DRIVERS

- Market and Export Infrastructure
- Surface Access, Pad Drilling, Terrain
- Logistics
- External Competition (LNG, shrinking markets)
- Development Well Costs < $12m
- Political Will
- Service Support
- Favourable Legislation to Support Exploration
- Multi-billion $ Capital Investment

The Opportunity

- The Chaco Plain has the potential to be a world-class tight gas petroleum province
- Could provide Bolivia with a resource of national significance
- Readily double national reserves (10 TCF, >800 wells) and off set existing production declines
- The play is readily de-risked with only a few key exploration wells
- Resource play development:
  - Beneficially impacts local businesses, increases employment opportunities, and boosts regional and national economies
  - Spans decades with field life cycles > 50 years
  - Requires the investment of many billions of dollars
- Super Pad Drilling limits surface and cultural impact
- Could underwrite LNG Export (e.g. CBM to LNG in Australia)
- Engage local communities at EVERY stage in the development