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.

References Cited


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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 $r_w$

$$p = p_{wf} + \frac{141.2q_w \mu_o B_o}{k\mu} \ln\left(\frac{r}{r_w}\right)$$
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
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
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.
Scale Analogue: Montney-Duvernay, Rockies

**Chaco Plain Devonian**
- Thickness: >2,200m thick

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

<table>
<thead>
<tr>
<th>Hydrocarbon Type</th>
<th>In-Place (from ERCB/AER Reports)</th>
<th>Marketable (this report)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Expected</td>
</tr>
<tr>
<td>Natural Gas - billion m³ (trillion cubic feet)</td>
<td>48,124 (1,199)</td>
<td>65,415 (2,309)</td>
</tr>
<tr>
<td>NGLs - million m³ (million barrels)</td>
<td>1,910 (12,020)</td>
<td>4,863 (30,599)</td>
</tr>
<tr>
<td>Oil - million m³ (million barrels)</td>
<td>12,654 (79,621)</td>
<td>22,045 (138,706)</td>
</tr>
</tbody>
</table>

Ultimate potential for Montney, including lowermost Doig siltstone, Alberta/BC
Development Analogue: DJ Basin, Rockies

Niobrara Petroleum System - Denver Basin
Shallow Biogenic Gas
Deep Thermogenic Oil and Gas

300 km

Monthly Niobrara-DJ Oil & Gas Production

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

Technology is Transferable
Well Economics – 50/50 (Paradigm Shift)

N. Louisiana Economics

<table>
<thead>
<tr>
<th>Combined Lower Cotton Valley</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>EUR</td>
<td>12.1 Bcfe</td>
</tr>
<tr>
<td>EUR/1,000 ft. lateral</td>
<td>1.61Bcfe</td>
</tr>
<tr>
<td>Well Cost</td>
<td>$8.4 MM</td>
</tr>
<tr>
<td>Cost/1,000 ft. lateral</td>
<td>$1,120 K</td>
</tr>
<tr>
<td>Lateral Length</td>
<td>7.500 ft.</td>
</tr>
<tr>
<td>IRR* - $3.00</td>
<td>33%</td>
</tr>
<tr>
<td>IRR at Strip as of 12/29/17</td>
<td>27%</td>
</tr>
</tbody>
</table>

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
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

36 well pads
810 lateral sections
# Development Drivers – Chaco Plain

<table>
<thead>
<tr>
<th>TECHNICAL DRIVERS</th>
<th>COMMERCIAL DRIVERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Hydrocarbon Generation</td>
<td>• Market and Export Infrastructure</td>
</tr>
<tr>
<td>• Thickness / OGIP / GOR / Composition</td>
<td>• Surface Access, Pad Drilling, Terrain</td>
</tr>
<tr>
<td>• Pressure Regime, Burial and Maturity</td>
<td>• Logistics</td>
</tr>
<tr>
<td>• Gas Chemistry</td>
<td>• External Competition (LNG, shrinking markets)</td>
</tr>
<tr>
<td>• Reservoir / Regional Sandstone Distribution</td>
<td>• Development Well Costs &lt; $12m</td>
</tr>
<tr>
<td>• Inversion / Erosion / In situ Tectonic Stress</td>
<td>• Political Will</td>
</tr>
<tr>
<td>• Water Saturation / Moveable Water</td>
<td>• Service Support</td>
</tr>
<tr>
<td>• Reservoir Compartmentalisation</td>
<td>• Favourable Legislation to Support Exploration</td>
</tr>
<tr>
<td>• Matrix Permeability and TGS Porosity</td>
<td>• Multi-billion $ Capital Investment</td>
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*CanCambria*
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 offset 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