Formation Evaluation in Shale Prospects Experience in Argentina Vaca Muerta Formation*

Martin Paris¹

Search and Discovery Article #51082 (2015)**
Posted March 30, 2015

*Adapted from oral presentation given at AAPG Geoscience Technology Workshop, Expanding Unconventional Resources in Colombia with New Science – From Heavy Oil to Shale Gas/Shale Oil Opportunities, Bogota, Colombia, December 10-11, 2014
**Datapages © 2015 Serial rights given by author. For all other rights contact author directly.

¹Geoscience Coordinator, Baker Hughes, Buenos Aires, Argentina (Martin.Paris@bakerhughes.com)

Abstract

Although the terms "formation evaluation" are equally applied to both conventional reservoirs and shale prospects, their objectives, log-based quantifiable properties, lab measurements, and processes are distinctly different. This demands a change in workflows, mindset and paradigms of the Geoscience professionals, who had to walk through the learning curve at a fast rate, with the support of experience in the U.S.A. In Argentina, with over three years of learning in the Vaca Muerta Formation, a workflow has been created to evaluate this formation. This workflow, which encompasses log analyses, lab measurements and calibrations, is presented in this paper. Relevant properties must be summarized following quantification to proceed to decision-making. This is aimed at answering some questions, such as: Which intervals should be hydraulically fractured and which intervals should not? Which is the best interval to navigate in a horizontal well? It is worth mentioning that there are many properties that could be major drivers that determine the productivity of this prospect, being added and studied
progressively and methodically as projects move forward. Therefore, formation evaluation in unconventional prospects should not be deemed as the final product of a static science, because, as any process of knowledge creation, it evolves over time.

**References Cited**


Formation Evaluation in Shale Prospects
Experience in Argentina
Vaca Muerta Formation

Martin Paris
# Formation Evaluation

## Conventional Reservoirs vs. Shales

<table>
<thead>
<tr>
<th>Property</th>
<th>Conventional Reservoirs</th>
<th>Shales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total/effective porosity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permeability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sw</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capillary pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td>...</td>
</tr>
<tr>
<td>TOC / %Ro / S1</td>
<td></td>
<td>Fracturability</td>
</tr>
<tr>
<td>Britleness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural fractures</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Objective

- **Quantify Reserves**
- **Hydraulic Fracture Design**

---

**What means FE?**
Overview

- Petrophysical Evaluation Shale Reservoir Vaca Muerta Fm. – Log suite
- Workflow
- Unconventional Sweet Spot
  - Mineralogy Log
  - Porosity
  - TOC
  - Brittleness & Mech Prop
- Why new geomechanical models?
- Traffic Lights and Validation
- Lessons Learned
Overview

- We have learned from the Vaca Muerta Formation along three years

- What we know

- What we know we do not know

Uncertainties
Neuquén Basin Location
Reservoirs in the Neuquén Basin
Petrophysical Evaluation Shale Reservoir Vaca Muerta Fm.
Technologies Involved in Quantifying Reservoir Characteristics

Resistivity / Density / Neutron

Mineralogy Log
- Lithology
- Mineralogy
- TOC
- Facies

Image Logs
- Structural and Sedimentary analysis
- Stress regime determination
- Fracture detection and characterization

Sidewall Core
- Core analysis (Phi, k, DRX, TOC, ...)
- Geomechanical analysis

NMR
- Porosity
- TOC
- Fluid characterization

Cross Dipole
- Acoustic
- Geomechanical properties
Outcrops

- Lithofacies
  - Limestones
    - Planar natural fractures
    - Low embedment
  - Marls
    - Dendritic natural fractures
    - High embedment
  - Uncertainty Sometimes fractures on limestone are filled with calcite or gypsum. If this natural fractures are re-opened during fracking. Calcite or gypsum could seal the production (at least in one of the faces).

- Other features
  - Nodules
  - Beef (Thickness: 1 to 10 cm. Overpressure in source rock)
  - Ash bed (High Uncertainty) Thickness: 1 to 5 cm. Volcanic origin. Difficult propagation of hydraulic fracture. High embedment
Unconventional Sweet Spot Characteristics

TOC
Kerogen Type
Fluid
Maturity
Depositional
Environment

Geochemical

Geomechanical

Anisotropy
Stress Regime
Fractures
Faulting
Brittleness

Geological

Depth
Thickness
Lithology/Mineralogy
Porosity
Pressure

Sweet Spot
Mineralogy Log

- INPUT – PROCESS - OUTPUT
To bear in mind

DRX LAB’s Comparison

- Minor uncertainty in Quartz.
- Greater uncertainty in Total Clay.

Taken from
CONEXPLO 2014, Argentina
TOTAL CARBON = INORGANIC CARBON + ORGANIC CARBON
Best Practices
Samples are taken from the center of the rotary sidewall cores, assuming that OBM failed to reach the center of the core, as this is a low permeability formation. Here, the TOC values obtained are more consistent with the regional knowledge of the formation.
TOC

TOC from FLEX (solid line) and from LAB’s (dots)

LAB 1 (sidewall core)

LAB 1 (cutting)

LAB 2 (sidewall core)

TOC from FLEX

Quintuco Fm.

Vaca Muerta Fm.

Tordillo Fm.
LAB porosity shows a perfect fit with NMR effective porosity.

Total porosity is used in geomechanics and petrophysics calculations.
Brittleness

Brittleness Indicators computed from:
- Mineralogy: Mineralogy Brittleness Index
  - Studies in several shale plays suggest that as the amounts of silica and carbonate present in the rock increases the rock’s brittleness increases.
  - \[ BIM = \begin{align*} \frac{\text{wt. fraction QFM + CARB}}{\text{wt. fraction QFM + CARB + CLV + TOC}} \end{align*} \]
  - Generally, the higher the BIM the more brittle the interval.

Geomechanical brittleness and hardness
- Britteness Index: Derived from Young’s Modulus and Poisson’s Ratio.
  - A high Young’s Modulus (E) and/or a low Poisson’s Ratio (v) indicate brittle rock behavior

Brittleness = \[ \frac{E_{\text{index}} + V_{\text{index}}}{2} \]

Geomechanical

Why new geomechanical models?

Orthotropic Model

Transverse Isotropic Model (VTI)

ARMA 12-644
Orthotropic Horizontal Stress Characterization from Logging and Core- Derived Acoustic Anisotropies
Franquet, J.A. and Rodriguez, E.F.
Baker Hughes, Houston, TX, USA
Building a Geomechanical Model
Traffic Lights

Brittleness < 0.33
Dif. Pressure > 2800psi

Brittleness > 0.37
Phi > 5%
TOC > 2%
Vclay < 30%
Dif. Pressure < 2000psi
Fracture Stages
GeoMechanical Model Validation

Stage #1
Stage #2
Stage #3

FPG (Fracture Pressure Gradient)
CLPG (Closure Pressure Gradient)
Fracture Pressure Gradient (DFIT)
Perforation
Lessons Learned

- A workflow is developed for the Vaca Muerta Formation
- During the exploration phase of the evaluation of a shale prospect
  - Logs with laboratory data calibration is necessary (DRX, TOC, petrophysics).
  - However there is great uncertainty in determining the mineralogy
  - LAB porosity shows a perfect fit with NMR effective porosity.
  - TOC can be calculated from Logs with great certainty.
- Always bear in mind the uncertainties
  - Ash beds
  - Natural fractures (open, healed)
  - Pore Pressure Mineralogy
  - Brittleness
  - ...
THANK YOU