[PS]Predicting Recoverable Liquid-Rich Sweet-Spots with PVT Phase Kinetic Modeling: Vaca Muerta Shale, Neuquén Embayment*

Guillermo Pérez-Drago[1], Mariana Alvis[1], Pierre-Yves Chenet[1], and Felipe Medellin[1]

Search and Discovery Article #42245 (2018)**
Posted July 30, 2018

*Adapted from poster presentation given at 2018 AAPG Annual Convention & Exhibition, Salt Lake City, Utah, May 20-23, 2018

[1]Beicip-Franlab, Rueil-Malmaison, France (guillermo.perez-drago@beicip.com)

Abstract

Prediction of hydrocarbon composition and fluid phase behavior, in function of dew and bubble points, is essential to appraise shale play resources and delineation of recoverable sweet-spots. Sweet-spot detection is based on shale play fairway analysis in order to identify areas with significant retained hydrocarbons in-place but also specific fluid behavior at reservoir conditions (close to critical point) optimal liquid-rich maximum recovery.

For this purpose, we developed a customized household compositional kinetic model for hydrocarbon generation coupled with 1D PVT reservoir fluid modeling (Peng Robinson EOS) for detailed fluid phase behavior properties. The defined kerogen and the associated source rock type fractions react as a function of thermal stress throughout primary and secondary cracking, being possible to quantify the compositional yields (mole fraction) of in-situ retained gas and liquid fractions. Hydrocarbons in-place at reservoir conditions were estimated by net source rock thickness organic porosity development, taking into account the generation of immobile fractions during secondary cracking.

Calculated mole fractions and reservoir conditions (P-T) were used as inputs for PVT modeling to predict fluid phase diagrams as a function of critical point and to create maps of volumetric properties such as Bo, Bg, initial GOR and CGR. Volumetric factors maps were used to quantify hydrocarbon volumes in place at surface conditions. Finally, based on existing production data and forecast profiles (using adapted Arps equation), it was possible to define recovery factors to map recoverable resources in MMstbl/km and Bscf/km.

This workflow has been applied using public data from the Lower and Upper sections of the marine organic-rich Vaca Muerta Shale Play in the Neuquén Embayment. Calibration with production data comes from developed YPF's Loma Campana concession block. Results provide a precise position of fluid type limits and detailed PVT properties in less developed areas for volatile oil and retrograde gas condensate windows. Higher potential of recoverable liquid-rich sweet-spots are located in areas where fluid behavior at reservoir conditions is near the condensate-volatile oil limit, close to critical point. Herein ultimate recoverable oil and gas resources vary from 0.7-1.1 MMstb/km and 3.0-6.5 Bscf/km. Detecting recoverable sweet-spots provides, thus, a significant step forward for shale resource assessment and bidding block ranking.

Predicting Recoverable Liquid-Rich Sweet-Spots with PVT Phase Kinetic Modeling: Vaca Muerta Shale, Neuquén Embayment

G. Pérez-Drago*, M. Alvis *, P. Chenet *, F. Medellin **

* Beicip-Franlab, Rueil-Malmaison, France

** Beicip Inc, Houston, Texas, U.S.A.

AAPG ACE 2018 — 20-23 May 2018 · Salt Lake City, Utah — ANNUAL CONVENTION & EXHIBITION

1. OBJECTIVE

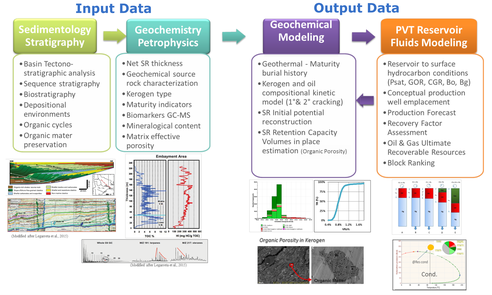
The objective is to develop an E&P integrated workflow for unconventional shale plays aiming at quantifying:

- The hydrocarbon fluid type, composition and PVT phase behavior properties in function of dew and bubble points
- The Ultimate Recoverable Oil and Gas Resources
- The Oil and gas recovery factors and production rate forecast

2. WORKFLOW - METHODOLOGY

The workflow aims at reducing the uncertainty on prospective resources assessments and at identifying potential sweet spots prior to systematic drilling. It is based on Shale Play Fairway Analysis in order to identify areas with significant retained hydrocarbons in-place but also specific fluid behavior at reservoir conditions for optimal liquid-rich maximum recovery.

The Workflow integrates:
- Geochemical Modeling: thermal cracking of kerogen and oil -> Compositional Kinetic Modeling
- Reservoir Fluid PVT Modeling: Hydrocarbon phase state -> EOS

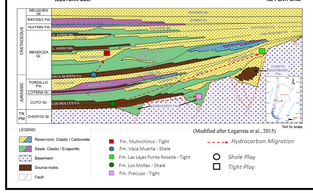


3. CASE STUDY SETTINGS

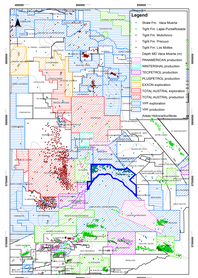
The Vaca Muerta Shale Play is located in the Neuquén Embayment in west-central Argentina. It consists of dark marine organic-rich shales deposited in distal deep marine environments, developed from the Early Tithonian to Early Valanginian (post-rift back-arc stage deposition phase). It represents a regional transgression event (anoxic conditions) associated with condensed sections able to preserve organic matter. There are two Members: Upper and Lower Vaca Muerta with decreasing organic-mater content towards the top with a more calcareous shale matrix.

The Production from the shale play was identified in 2010 by YPF in the Loma Campana concession block. The Block is currently the main oil and associated gas producing area, contributing in 2016 with 88% of the shale production. It is located within the volatile oil and retrograde gas-condensate window. The production started with vertical and deviated wells and continued with horizontal wells which enhanced daily production rates. Until July 2017 Loma Campana produced 24 mbbls/day and 53 MMscf/day. Total production: 34 thousand BOEPD.

Neuquen Embayment Play Definition



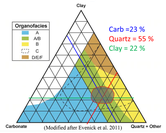
Neuquen E&P Blocks



4. SOURCE ROCK CHARACTERIZATION

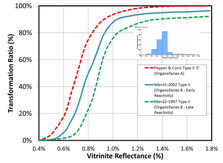
Source Rock characterization is based on geochemical and petrophysical analysis in order to estimate and reconstruct source rock initial potential before being affected by thermal maturity. The published input data and output parameters are summarized as follows:

Bulk Facies - Organic Facies

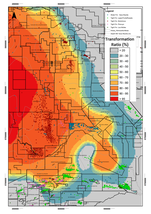


Vaca Muerta Source Rock Parameters:
- Net source rock thickness: 50 - 450 m
- Resiudal TOC :1 - 6 (wt%); HI: 150 - 450 (mg/g)
- Organofacies: A/B, Type II/IIS
- Maturity: VRo: 0.6 – 1.8%; Tmax: 428 – 490 °C; TR: 20 – 98 %
- Bulk Kinetics definition: Reactive Type II Menil-1 IFP
- TOC0 reconstruction: 2 - 9.5 (wt%); HI0: 450 – 550 (mg/g)

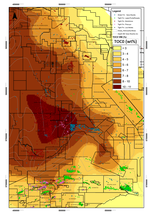
Bulk Kinetic Model



Transformation Ratio (%)



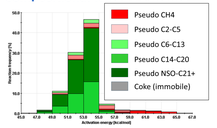
TOC0 Lower Vaca Muerta (%)



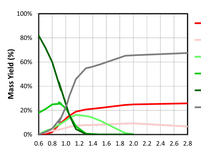
5. COMPOSITIONAL KINETIC MODEL

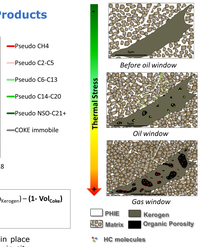
A Customized household compositional kinetic scheme was used. It consists of: 2 gas fractions, 3 oil fractions, 1 immobile solid fraction. The Kerogen and its initial HC fraction yield react as a function of thermal stress throughout primary and secondary cracking, being possible to quantify the compositional yields (mass yields) of in-situ retained gas and liquid fractions.

Compositional Kinetic Scheme

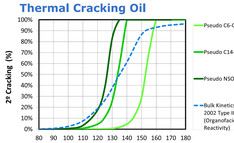


In-situ 1° and 2° Cracking Products





Thermal Cracking Oil

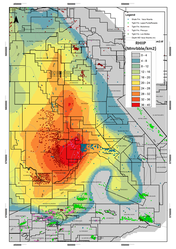


$$PHIOrg = TOC0 * HI0 * TR * (1 - PHIE) * (\rho_{Block\,Matrix} / \rho_{Kerogen}) - (1 - Vol_{Coke})$$

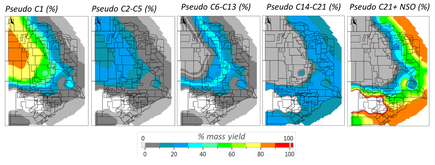
$$RHIIP = (PHIOrg * Net\ SR\ Thickness)$$

The Retention capacity and volumes in place at reservoir conditions of in-situ hydrocarbons is directly obtained from of the organic porosity calculation. The organic porosity within the kerogen results from the transformation of kerogen into mobile hydrocarbons. When solid products are formed as a consequence of secondary cracking, the organic porosity decreases. The model takes into account the generation of immobile fractions during secondary cracking. The HC saturation within the organic porosity is 100%.

RHIIP (MMrbble/km²)



Compositional Mass Yields from Thermal Cracking



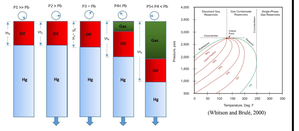
6. PVT RESERVOIR FLUID MODELING

The Simulated in-situ retained mass fractions (converted to molar fractions) were used as inputs to perform PVT fluid modeling (PVTFlow® software), aiming to predict fluid phase behavior at reservoir conditions (P-T).

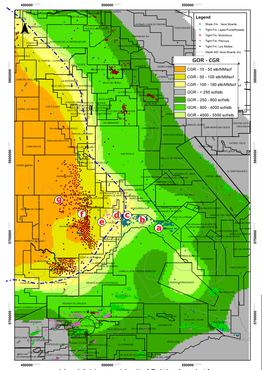
An equation of state (Peng Robinson 2) was applied to relate pressure to temperature and volume and to predict fluid properties (selected experiments: saturation pressure and flash).

Several 1D PVT Models were defined along the Neuquen Embayment (from a to g) in order to investigate the behavior of the reservoir fluids (from low to high mature areas). For a given fluid, its behavior is determined by the shape of phase diagram and the position of its critical point. Results allow to define the composition of oil and gas fluids type present on the area, getting detailed PVT properties in Vaca Muerta Shale Play for volatile oil (a, b & c) and retrograde gas condensate windows (d to g).

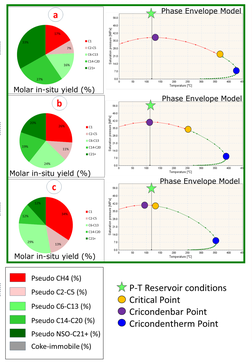
PVT Analysis Concept



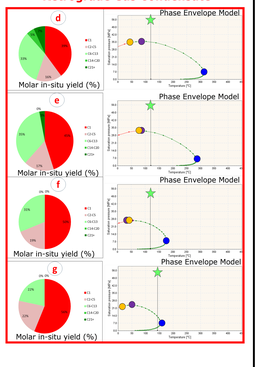
In-situ GOR (scf/stb) - CGR (stb/MMscf)



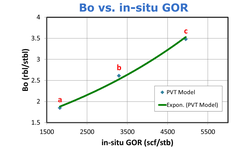
Volatile Oil



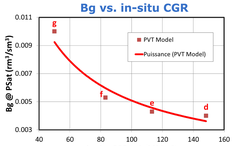
Retrograde Gas Condensate



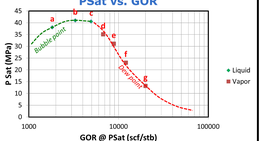
Bo vs. in-situ GOR



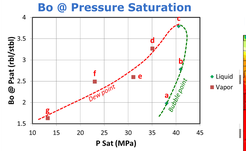
Bg vs. in-situ CGR



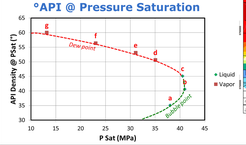
PSat vs. GOR



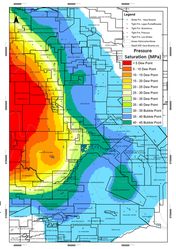
Bo @ Pressure Saturation



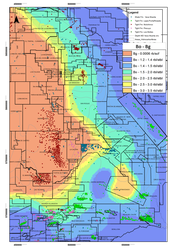
°API @ Pressure Saturation



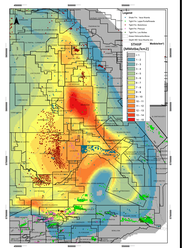
Pressure Saturation (MPa)



Bo - Bg (rm3/sm3)



STOIIP (MMstbe/km²)



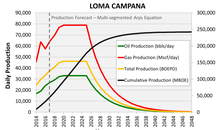
7. RECOVERABLE RESOURCES

Production forecast was performed by applying multi-segmented decline along with Arps equations; which were calibrated with observed initial rates per well type and annual decline rates to estimate recovery at long term (EUR).

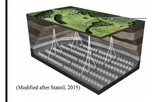
The Recovery factors were estimated from forecasted production by block, assuming a conceptual well density and future drilling rate (1.8 - 2.0 well/km², 20-190 wells per year); and the estimated volumes of oil and gas initially in place at surface conditions. Recovery factors were estimated for oil and gas from each phase.

The higher potential of recoverable liquid-rich resources is located in areas where fluid behavior at reservoir conditions is near the condensate-volatile oil limit, close to critical point. These areas can be considered as sweet spots.

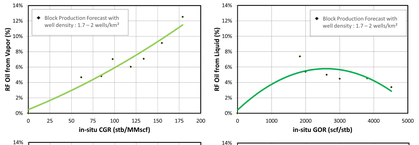
Loma Campana Production Forecast



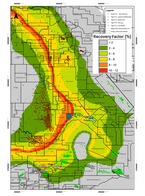
Conceptual production well emplacement

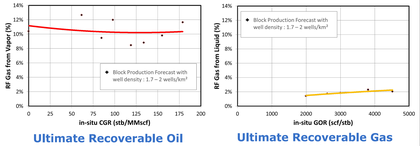


Oil and Gas Recovery Factors

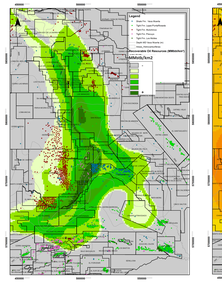


Recovery Factor Oil (%)

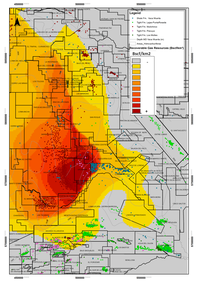




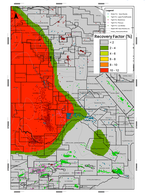
Ultimate Recoverable Oil (MMstb/km²)



Ultimate Recoverable Gas (Bscf/km²)



Recovery Factor Gas (%)



8. CONCLUSIONS - REFERENCES

An integrated E&P geochemical and reservoir fluid modeling workflow was proposed in order to predict and quantify ultimate recoverable oil and gas resources in Vaca Muerta Shale Slay through a shale play fairway analysis approach.

The Results show that the recoverable resources have a direct relationship between retained in-situ hydrocarbon quantities (in function of initial organic matter volume and maturity), fluid composition and phase behavior at reservoir conditions (Pressure Saturation in bubble and dew points). The High liquid-rich recovery occurs at high pressure saturation near the condensate-volatile oil limit, close to critical point. In these areas, which may be considered as potential sweet spots (low risk areas), the ultimate recoverable oil and gas resources vary from 0.7-1.1 MMstb/km² and 3.0-6.5 Bscf/km².

References:

1. Sylwan, C. 2014. Source rock properties of Vaca Muerta Formation, Neuquen Basin, Argentina. Pan American Energy L.L.C.
2. Leonardo Legarreta, Patagonia Exploración S.A. and Héctor J. Villar, GeoLab Sur S.A., 2015. The Vaca Muerta Formation (Late Jurassic - Early Cretaceous), Neuquén Basin, Argentina: Sequences, Facies and Source Rock Characteristics. Unconventional Resources Technology Conference (URTeC)
3. Nicolas Gutierrez Schmidt, Julio C. Alonso, Adolfo Giusiano, Cecilia Lauri, Thamy Salas, 2014. El Shale de la Formación Vaca Muerta: Integración de datos y estimación de recursos de petróleo y gas asociado Provincia de Neuquen. Subsecretaria de Minería e Hidrocarburos, Universidad Nacional de Río Negro.
3. Hamuli Molina, C., Alonso, M., 2016. Informe de producción de Petróleo y Gas en reservorios No convencionales Provincia de Neuquen.
4. Tagarot-Sead G., Vicente M., Luongo S. A., 2017. Historical production analysis of Vaca Muerta formation in the Neuquen Basin: a guide to understand the past, present and future. SPE-185519-MS.