Dealing with Poor Quality Data and Uncertainty in Petroleum System Modeling: An Example from the Fold and Thrust Belt of Bolivian Sub-Andean Ranges*

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Search and Discovery Article #42495 (2020)**

Posted January 27, 2020

*Adapted from oral presentation given at 2019 International Conference and Exhibition, Buenos Aires, Argentina, August 27-30, 2019
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Abstract

The petroleum systems of the Bolivian sub-Andean ranges were investigated utilizing data from both, wells and outcrops, to better understand the timing of hydrocarbon generation, expulsion and migration. Fields of Bolivian sub-Andean ranges currently produce around 2 BCF/d of natural gas with 2P reserves of 12.5 TCF. Kirusillas, Icla and Los Monos Middle Paleozoic age source rocks are responsible for the generation of hydrocarbons during periods of subsidence within the Cordilleran (Middle Paleozoic), Subandic (Upper Paleozoic) and Andic II (Paleogene to present) tectonic cycles. These source rocks typically have moderate to poor quality, characterized by low generation and expulsion efficiency. Due to the sparse and relatively poor-quality data available with respect to initial total organic carbon, source rock kinetics, ancient heat flow and actual maturity, the petroleum system modeling output generates a wide range of uncertainty. To mitigate this uncertainty, two different aspects were evaluated. First, critical factors that control the source rock such as hydrocarbon generation and expulsion were analyzed and integrated into a basin scale. Secondly, a probabilistic analysis of generation and expulsion timing, transformation ratio and critical moment was done, using different calibrated 1-D petroleum system models run by location, combining maximum and minimum values for the three key input parameters (source rock kinetics, heat flow and lithology). Models were calibrated with cores, logs, well tests, pressure data, Rock-Eval pyrolysis, vitrinite reflectance, thermal alteration index, and regional stratigraphic and structural cross sections. Additionally, a sensitivity analysis on the critical parameters was used to evaluate different outputs. Model results demonstrate that most of hydrocarbon generation is mainly before the Andean deformation during the Paleozoic and into the Mesozoic. Therefore, we should expect that some generated hydrocarbons would be expelled during both the Upper Paleozoic and Mesozoic times. Remaining volumes within these rocks would be expelled and migrate during Andean deformation through the main thrusts. These results are very encouraging for exploration of stratigraphic traps developed during the Upper Paleozoic and Mesozoic times.

References Cited


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## Thickness & Age

- Eroded Thickness

## Lithology

- Thermal Conductivity (Lithology & Porosity)

## TOC & oTOC (oHI)

## Pressure

## Expulsion Method / Saturation Threshold / Porosity

## Source Rocks

- TOC & oTOC (oHI)

## Kinetic

## Maturity
Wells & Field Sections Correlated & Calibrated with 2D seismic & Biostratigraphy

Perform and Analysis of Isopachs Maps

56 Wells & 23 Outcrops SR Geochemistry Analysis

Integrated with SR GDE, Ro, TOC Maps

1D PSM
Los Monos: 40 locations, 825 samples
Icla: 22 locations, 266 samples
Kirusillas: 5 locations, 10 samples
Parameters & Variables Quality Control: Mineralogy

Los Monos Fm. GDE (After Schneider et al. 2018)

- **Quartz**
- **Carbonate**
- **Claystone**

Los Monos avg. basin composition (Chavez et al., 2016)

TCB-1001 (Veizaga-Saavedra et al. 2018)

R-1012 II (Veizaga-Saavedra et al. 2018)

Camino Balapuca (Veizaga-Saavedra et al. 2018)
Parameters & Variables Quality Control: Maturity

After Pereira et al. 2017

Hernandez et al. 2011
Temperature vs. Maturity Calibration

Evidences of a Higher Paleo-Heat-Flow
Paleo-Heat-Flow: Basin Dynamics & Thermal Events

Current Heat Flow Represents 26 Ma of Paleo-Heat-Flow

Average Earth HF 6% higher than present

Ice Cap Subsidence & Uplift

Foreland vs Intracratonic

Intracratonic

Rift

Rifts

Foreland

Paleogene Gap

Lw K Gap

Lw Cb Gap

Tr Gap

Sillurian & Devonian Foreland Basin

Carboniferous "Tarija Basin"

Jurassic "Villamontes Basin"

Cretaceous "Santa Cruz & Salta Basins"

Cenozoic "Andean Basin"

Devonian

Permian

Triassic

Jurassic

Cretaceous

Mesozoic

Paleozoic

Early

Middle

Late

Early

Middle

Late

Early

Middle

Late

Early

Middle

Late

Eocene

Cenozoic

Lw Cb Gap

Tr Gap

Lw K Gap

Paleogene Gap

Ice Cap Subsidence & Uplift

Foreland vs Intracratonic

Intracratonic

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Cenozoic "Andean Basin"

Devonian

Permian

Triassic

Jurassic

Cretaceous

Mesozoic

Paleozoic

Early

Middle

Late

Early

Middle

Late

Early

Middle

Late

Early

Middle

Late

Eocene

Cenozoic
Overlapping Source Rock Transformation Ratio Diagrams

Steady-State Heat Flow

Los Monos Average Geochemistry (Chavez et al., 2016)

Type III

50% Type II & 50% Type III

DRX Tacobox-1 Geochemistry

Type III

50% Type II & 50% Type III

with Jurassic Rifting Heat Flow
Overlapping Source Rock Transformation Ratio Diagrams

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50% Type II & 50% Type III

Type III

50% Type II & 50% Type III
Overlapping Source Rock Transformation Ratio Diagrams

Steady-State Heat Flow with Jurassic Rifting Heat Flow

<table>
<thead>
<tr>
<th>Paleozoic</th>
<th>Devonian</th>
<th>Carboniferous</th>
<th>Permian</th>
<th>Triassic</th>
<th>Mesozoic</th>
<th>Jurassic</th>
<th>Cretaceous</th>
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Transformation Ratio (fraction)

- 1
- 2-3
- 4-5
- 6-7-8

Age (my)
Kirusillas Fm. Source Rock Transformation Ratio Diagram

Kirusillas Ro Maturity Map

2.11 Ro
1.76 Ro
1.93 Ro

Tacobo
Madrejones
Icla Fm. Source Rock Transformation Ratio Diagram

Icla Ro Maturity Map
(After Schneider et al. 2018)
Los Monos Fm. Source Rock Transformation Ratio Diagram

Los Monos Ro Maturity Map
(After Schneider et al. 2018)
• Wide range of uncertainty in the petroleum system modeling due to complex tectonic evolution, and for Icla and Kirusillas Source Rocks sparse and relatively poor quality data available for calibration.

• A probabilistic analysis of generation timing, transformation ratio and critical moment was done, using different calibrated 1-D petroleum system models run by location, combining maximum and minimum values for the three key input parameters.

• Kirusillas Fm. modeling shows that most of hydrocarbon generation is during the Upper Paleozoic.

• Icla Fm. modeling shows that generation started in the Upper Paleozoic, reaching the base of Cenozoic with more than 50% of the Transformation Ratio. Variation between North and South are related to an combination of the thickening of Upper Paleozoic to the South and higher Heat Flow.

• Generation timing for the Los Monos Fm. started during the Permian/Mesozoic and continued up to the present, with high sensibility to adding of a Mesozoic Thermal Event.
Thank You


