PS Fluid Flow Behaviors Under Architectural Controls of the Wall Creek Member in the Frontier Formation: Western Powder River Basin, Wyoming*

Tuan T. Le[1], Todd Hoffman[1], Nathan La Fontaine[2], and Michael Hofmann[2]

Search and Discovery Article #20435 (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]Petroleum Engineering, Montana Tech, Butte, Montana (tle@mtech.edu)
[2]University of Montana, Missoula, Montana

Abstract

The Frontier Formation in the Powder River Basin has been re-discovered for oil and gas potential with the development of long horizontal wells and multi-stage hydraulic fracturing. Over the last decade, the Wall Creek Member (WCM) of the Frontier Formation has proven to be a successful hydrocarbon-producing target, yet a full understanding of this complex stratigraphic unit has not been fully achieved. Tisdale Anticline outcrop studies conducted by University of Montana have shown that thickening upward tidal bars within WCM play an important role in hydrocarbon production. Recent studies have analyzed the geometry and extent of muddy toe-sets within tidal bars to affect fluid flow behavior. Furthermore, the fluid and rock properties have uncertainty and are not well defined due to the low permeability rocks. This study aims to describe the fluid flow behaviors of these features and create a regional outcrop model (1 km by 1 km) that includes all the reservoir properties and geologic features to better understand hydrocarbon recovery.

This project consists of defining the reservoir properties and upscaling the permeability of defined geocellular models with different geologic features into the reservoir model for the WCM. A single horizontal well flow simulation model was created to estimate the reservoir properties. Using three offset well logs, a 32 feet interval was selected to represent the net pay zone of the Wall Creek. The porosity was estimated using well logs, and permeability was established by applying a correlation of porosity and permeability found from core data. The historical production was matched by modifying the initial fluid saturations and the rock physics parameters such as relative permeability and capillary pressure. As a result, representative fluid and rock physics models were obtained for regional model.

From the outcrop study, the defined geologic models (25 m by 1 5m) of 2 to 3 meters thick WCM tidal bars were created to include abundances and orientations of mud drapes as the most effective features of tidal bars. A regional model captures fine heterogeneities of tidal bars using flow-based upscaling of the geologic models. The effective directional permeabilities of each geologic scenario were obtained to create the

correlations between the mud drapes characteristics and effective permeability to create the regional model based on the outcrop observations. Results from the regional model are used to optimize field development.

References Cited

LaFontaine, N., 2018, Facies architecture and controls on reservoir behavior in the Turonian Wall Creek member of the Frontier Formation in the Powder River Basin, Wyoming: Graduate Student Theses, Dissertations, and Professional Papers.

Le, Tuan, 2018, Integrated stratigraphic controls for flow simulation of the Wall Creek Member in the Frontier Formation: Western Powder River Basin, Wyoming: Graduate Theses and Non-Theses, No. 159. Website accessed July 5, 2018. https://digitalcommons.mtech.edu/grad_rsch/159

Le, T., T. Hoffman, N. LaFontaine, and M. Hofmann, 2018, Integrated Stratigraphic Controls for Flow Simulation of the Wall Creek Member in the Frontier Formation: Western Powder River Basin, Wyoming: SPE 190095-MS, presented at SPE 2018 Western Regional Meeting, Garden Grove, California, 22-26 April.

Zupanic, J., M.H. Hofmann, and A. Hennes, 2016, Stratigraphic architecture and facies distribution within the Wall Creek member of the Frontier Formation, Western Powder River Basin, Wyoming: 2016 AAPG Annual Convention and Exhibition, Calgary, Alberta, Canada, June 19-22, 2016. AAPG/Datapages Search and Discovery Abstract #90259. Website accessed July 5, 2018. http://www.searchanddiscovery.com/abstracts/html/2016/90259ace/abstracts/2383125.html?q=%2BtextStrip%3Azupanic

Zupanic, J., 2017, Lateral heterogeneity and architectural analysis of the Wall Creek member of the Upper Cretaceous (Turonian) Frontier Formation: Graduate Student Theses, Dissertations, and Professional Papers, No. 11033. Website accessed July 5, 2018. https://scholarworks.umt.edu/etd/11033

FLUID FLOW BEHAVIOR UNDER ARCHITECTURAL CONTROLS OF THE WALL CREEK MEMBER IN THE FRONTIER FORMATION: WESTERN POWDER RIVER BASIN, WY

Authors: T. T. Le, T. Hoffman, N. La Fontaine, M. Hofmann

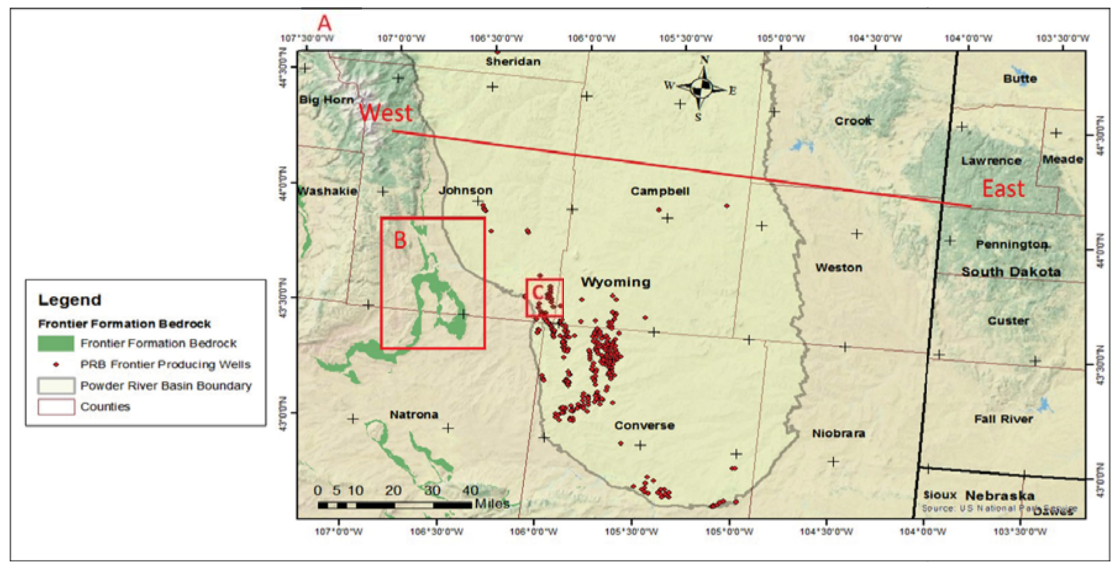


Figure 1: (A) Cross-section of geologic study and location of Frontier outcrop at the surface in Wyoming that associated with Frontier formation in Powder River Basin. (B) Tisdale Mountain Outcrop Study Area. (C) Reservoir Model Study.

The Frontier formation in the Powder River Basin has been re-discovered for oil and gas potential with the development of long horizontal wells and multi-stage hydraulic fracturing. Over the last decade, the Wall Creek member of the Frontier formation has proven to be a successful hydrocarbon-producing target, yet a full understanding of this complex structure has not been achieved.

GEOLOGY

The Powder River Basin is an asymmetric basin with near overturned dip on the West side and gentle sub horizontal dip to the East side of the basin.

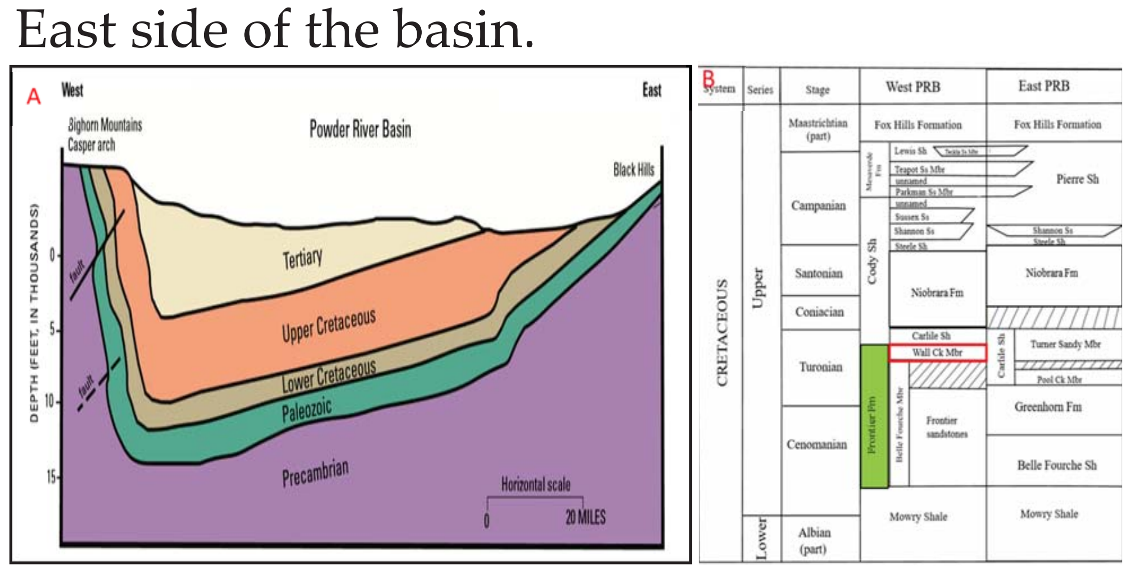


Figure 2: (A) Generalized west-east cross section of Powder River Basin. (B) Stratigraphic column of Upper Cretaceous strata in the Powder River Basin.

The complexity of the Wall Creek depositional environment has challenged geologists to understand the vertical and lateral heterogeneity of the play; furthermore, the fluid and rock properties have uncertainty and are not well-defined.

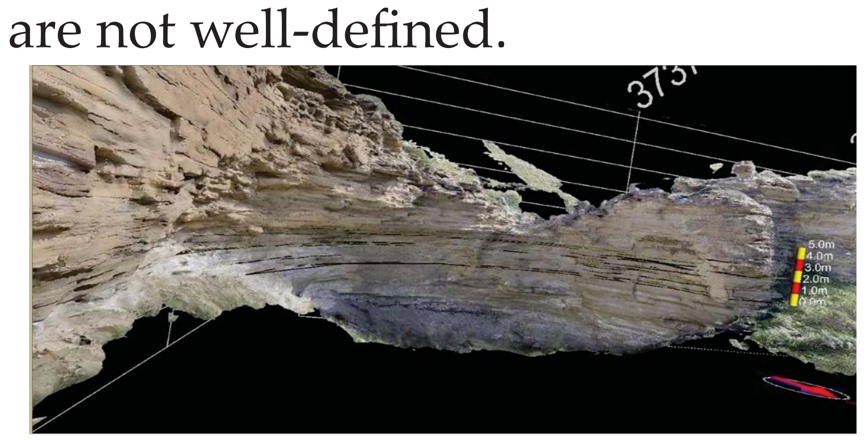


Figure 3: Example of heterogeneities of tidal bar facies inside Wall Creek Member observed from Tisdale Anticline outcrop. (Black traces represent mud drape visibility of the facies)

RESEARCH GOAL

Advance reservoir characterization understanding in the Frontier Formation in the Powder River Basin. Improve prospect definition and development strategy through a fully integrated outcrop to subsurface reservoir model. This project consists of two distinct aspects: (1) defining the reservoir properties through a well flow model and (2) upscaling the permeability of the outcrop models with different geologic features into a reservoir model for the WCM.

METHODOLOGY

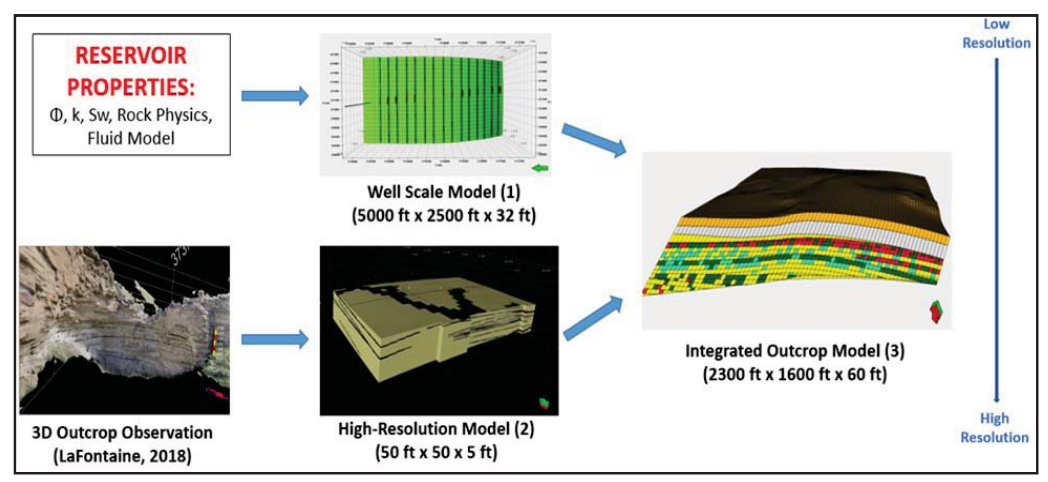


Figure 4: Workflow study to integrate the subsurface data and outcrop observation into full outcrop model.

1/ WELL SCALE MODEL

Rush State well located in section 36, T42N, R77W in Johnson county, WY.

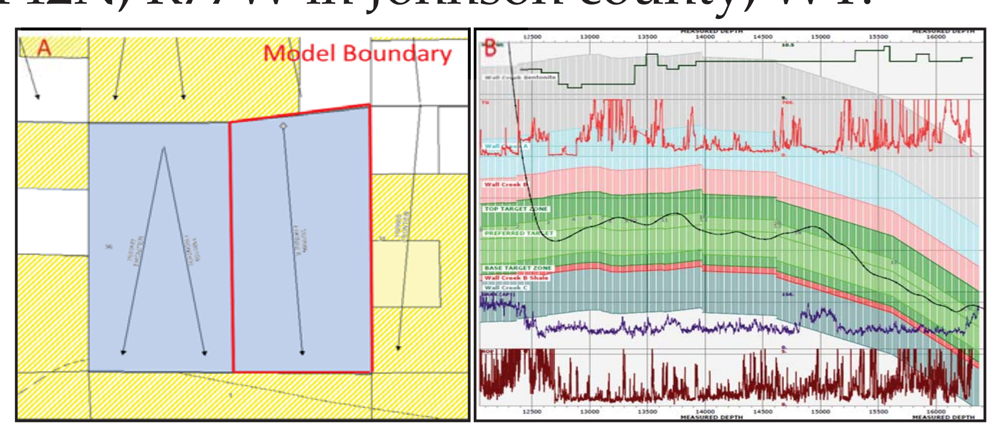


Figure 5: (A) Well location from GIS map and (B) well deviation from geosteering data.

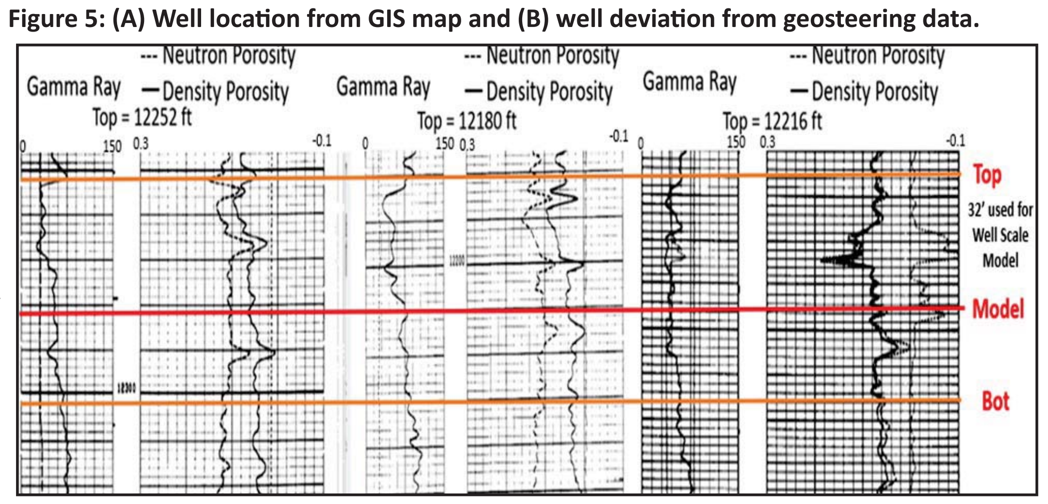


Figure 6: Well log pickings from three wells (50 ft thickness).

A/ Subsurface properties:

Reservoir pressure = 5,866 psia. R_s = 1.1 mscf/stb, Water salinity = 19,730 mg/L

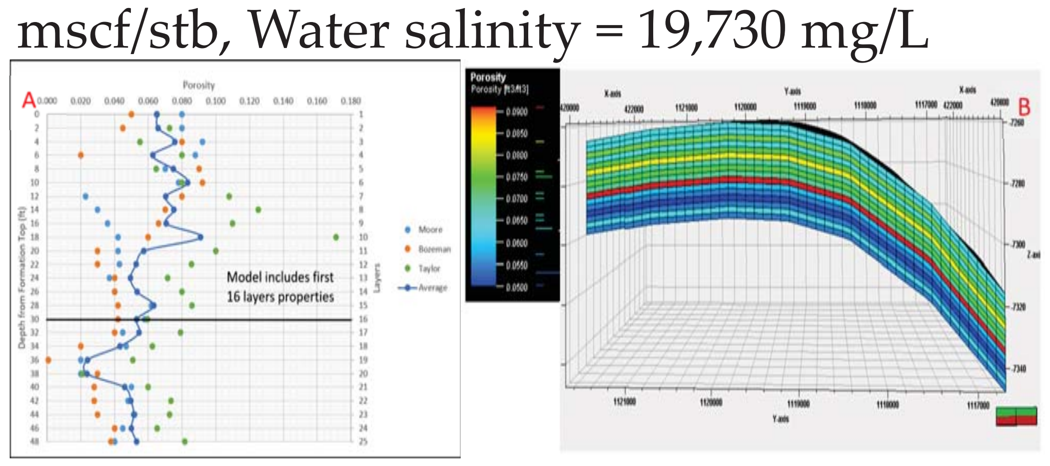


Figure 7: (A) Porosity estimation from well logs and (B) Petrel porosity model (ϕ = 5% - 9.1%).

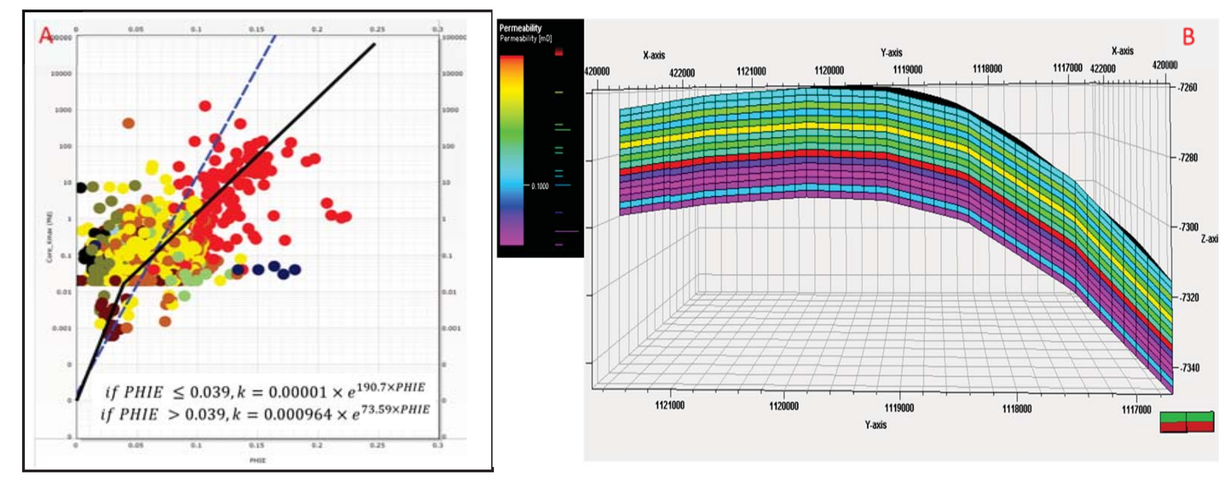


Figure 8: (A) Permeability estimations from Porosity-Permeability cross plot (including equation) and (B) Petrel permeability model (K = 0.0382 md—0.7806 md).

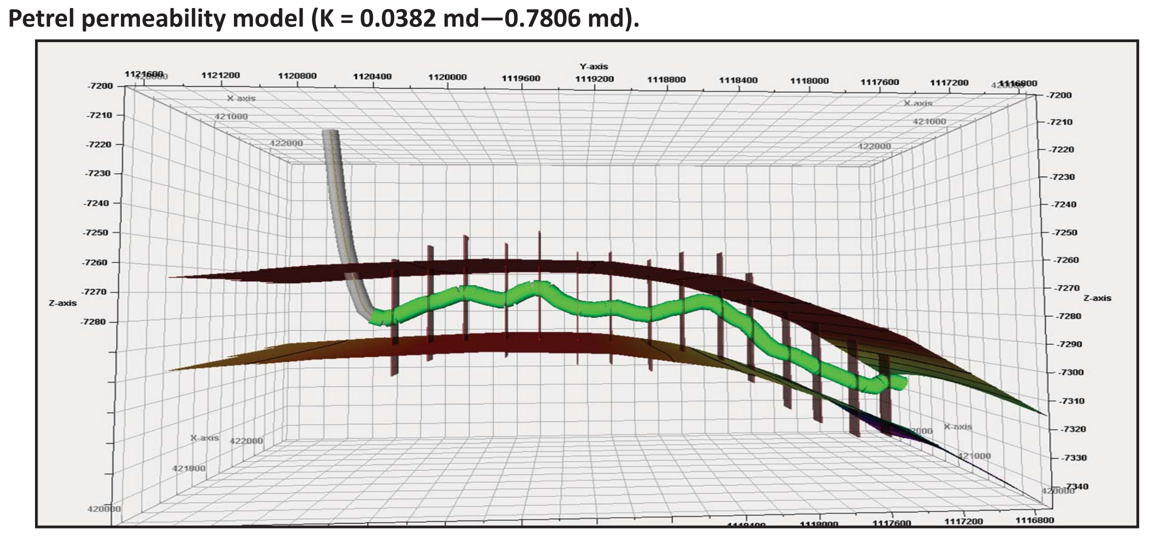


Figure 9: Completion model including sliding sleeve completion and 15 frac stages with 50 feet high and 100 feet half length for each fracture.

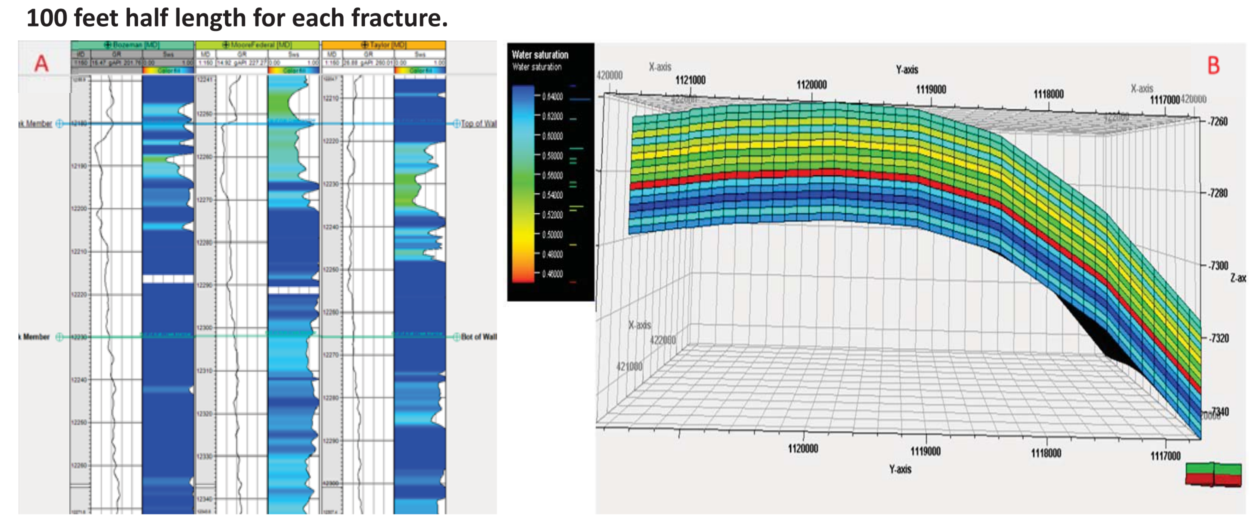


Figure 10: (A) Water saturation logs and (B) Petrel water saturation distribution model using porosity dependent (Sw = 45% - 65%).

B/ Fluid model:

Using PVTi software from Schlumberger simulation with Soave-Redlich-Kwong equation of state to match the fluid data.

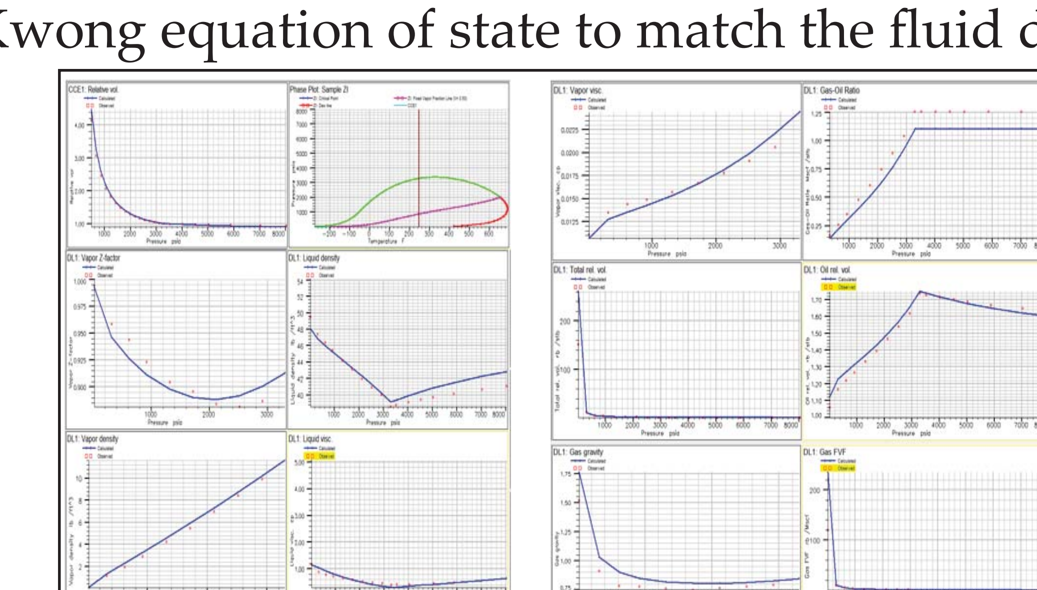


Figure 11: PVT matching results for fluid model. Red dots are PVT data, blue lines are matched model.

C/ Logarithmic Grid Refinement (LGR):

Using tartan grid to apply LGR into each hydraulic fracture: 25 grid cells in I direction with average cell size of 100 feet and LGR around frac with 10 divisions with minimum distance of 2 feet in J direction.

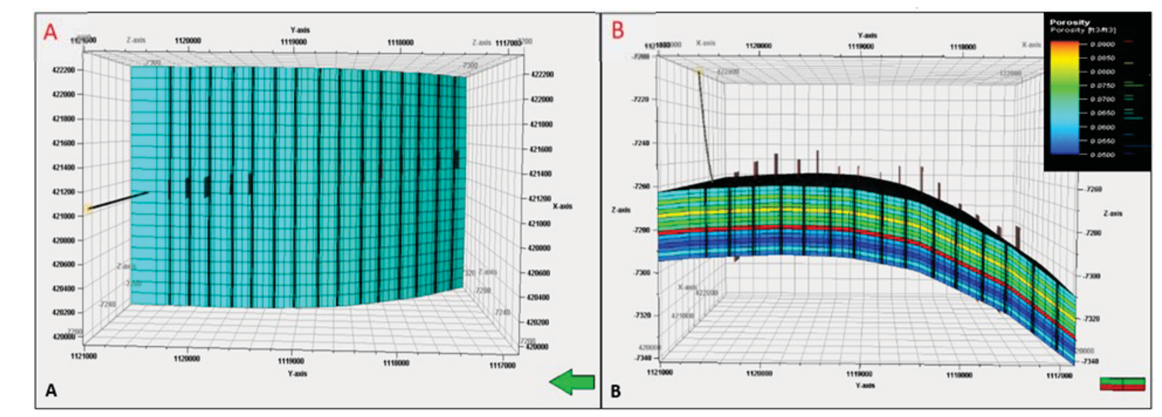


Figure 12: Top (A) and side (B) view of the Petrel reservoir model for a single horizontal well showing LGR application.

D/ Relative Permeability:

Using Corey equation to create relative permeability curve.

Table 1: Modified parameter for relative permeability curve

Parameter	Values
S_{or}	0.20
S_{wir}	0.35
S_{gr}	0.05
n_o to water	2.40
n_o to gas	3.00
n_w	6.00
n_g	2.65
$K_{ro,max}$	0.80

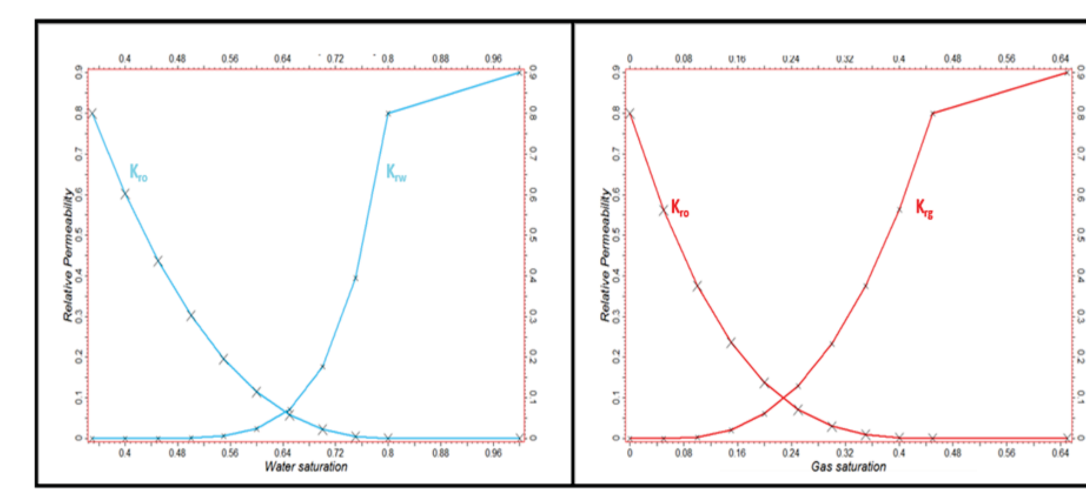


Figure 13: Relative permeability curves of oil, water and gas for the historical production matching.

E/ Sensitivity analysis:

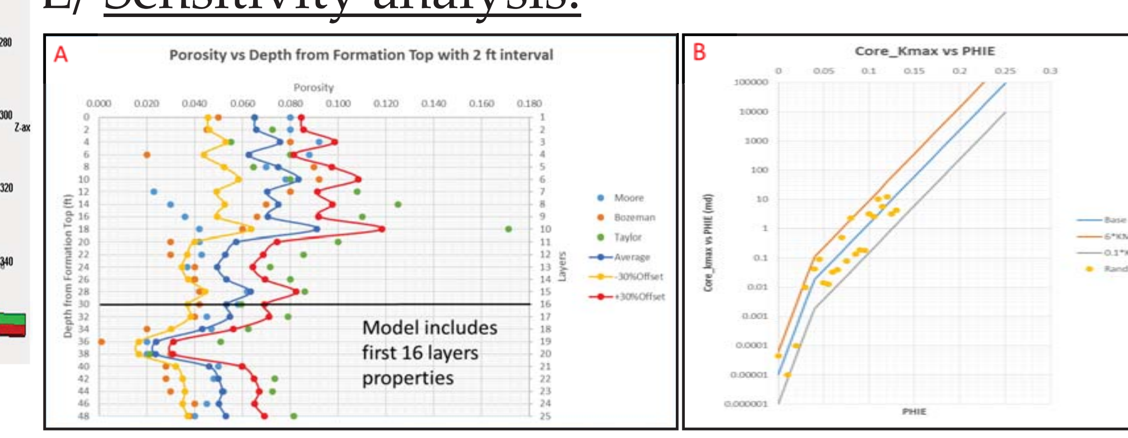


Figure 14: Sensitivity analysis for min and max porosity (A) and permeability (B).

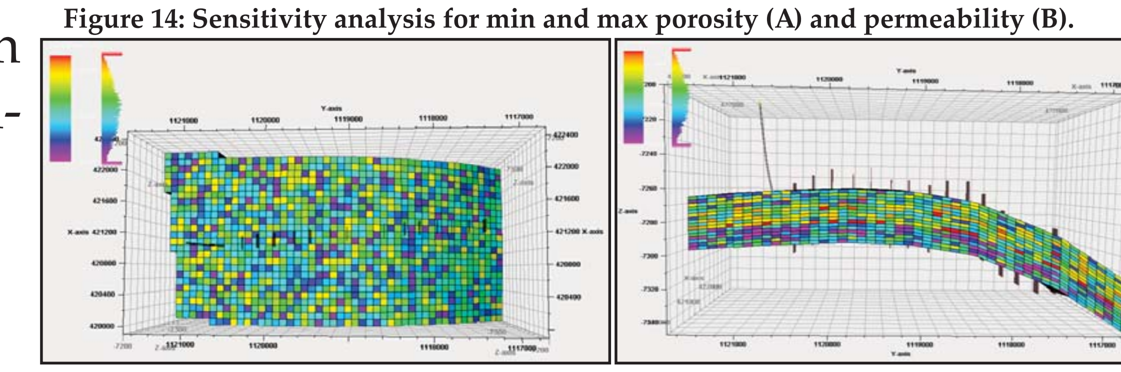


Figure 15: Sensitivity analysis for random distributed permeability of model.

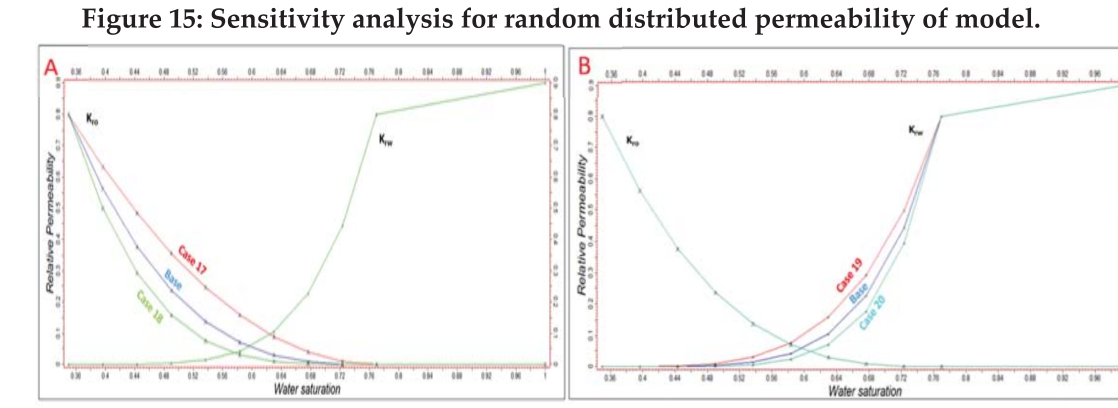


Figure 16: Sensitivity analysis for Corey Exponent of oil (A) and water (B) for relative permeability curve.

MontanaTech

FLUID FLOW BEHAVIOR UNDER ARCHITECTURAL CONTROLS OF THE WALL CREEK MEMBER IN THE FRONTIER FORMATION: WESTERN POWDER RIVER BASIN, WY

Authors: T. T. Le, T. Hoffman, N. La Fontaine, M. Hofmann

E/ Sensitivity analysis: (cont.)

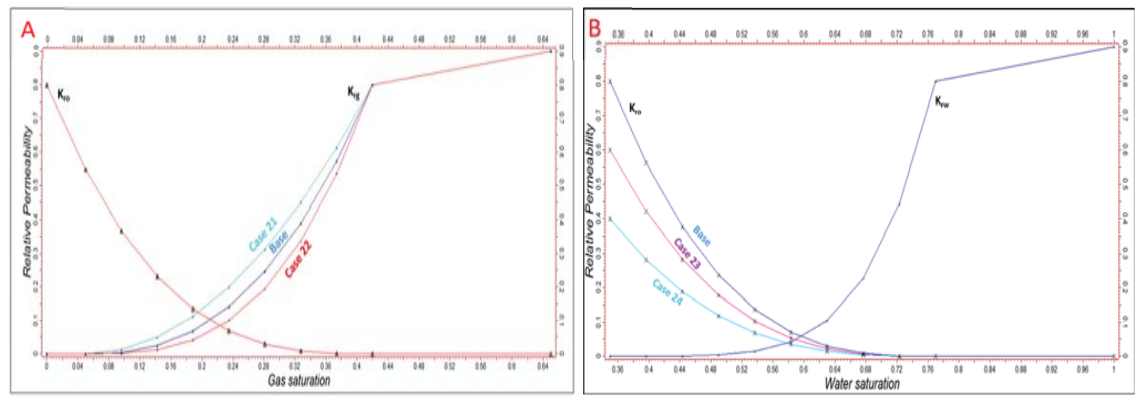


Figure 17: Sensitivity analysis for Corey exponent of gas (A) and K_{ro} at S_{omax} (B) of relative permeability curves.

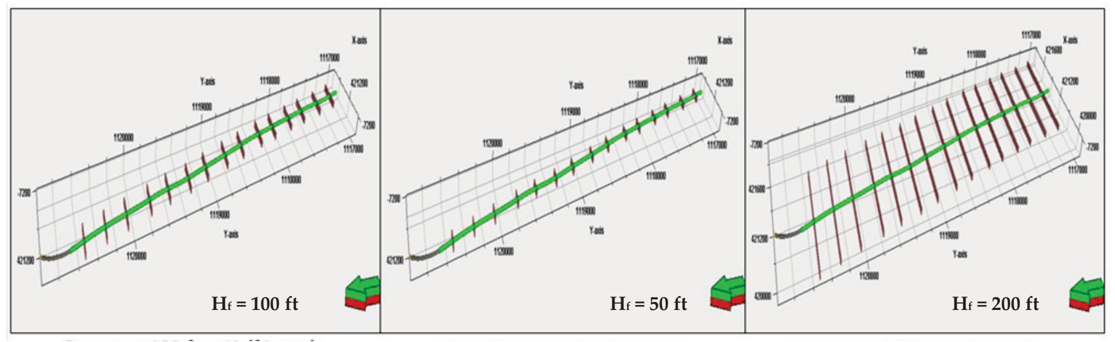


Figure 18: Sensitivity analysis for hydraulic fracture half-length of 100 feet, 50 feet, 200 feet for a single horizontal well of model.

Results:

- Permeability/porosity have largest impact on production.
- Random distributed permeability shows no significant difference.
- Relative permeability parameters are suitable for history matching purpose.
- Half length of hydraulic fracture has no big impact. 100 feet half length is good for simulation purpose.

F/ History Matching Results:

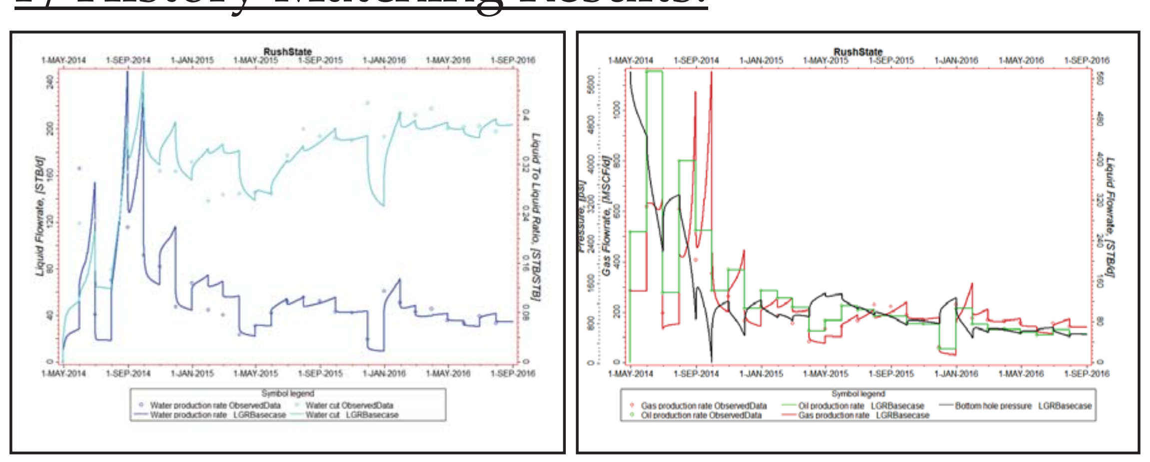
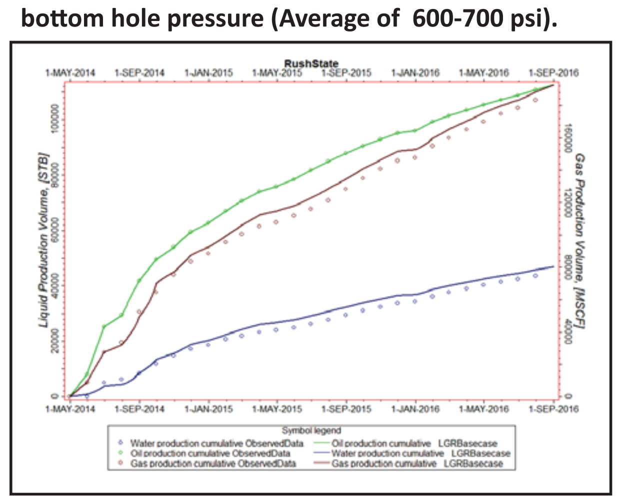


Figure 19: History matching results for oil, gas, water production and water cut with reasonable bottom hole pressure (Average of 600-700 psi).



- From the history data in 09/01/2016
  - Cumulative Oil Production = 112,539 STB
  - Cumulative Gas Production = 191,347MSCF
  - Cumulative Water Production = 45,927 STB
- From the model in 09/01/2016
  - Cumulative Oil Production = 112,539 STB
  - Cumulative Gas Production = 192,678 MSCF
  - Cumulative Water Production = 46,816 STB

Figure 20: History matching results of cumulative production of oil, gas, and water.

G/ Field Analysis:

Well spacing analysis and fracture spacing analysis were performed to optimize the spacing distances between the wells and between each fracture.

a/ Well Spacing Analysis: Fully developing the half-section reservoir.

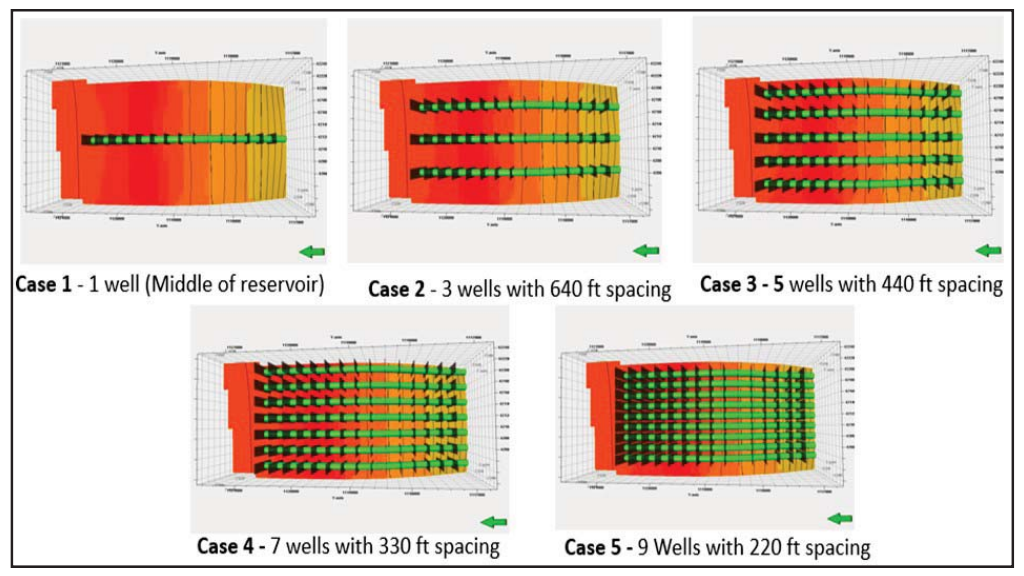


Figure 21: Well spacing analysis with five different cases.

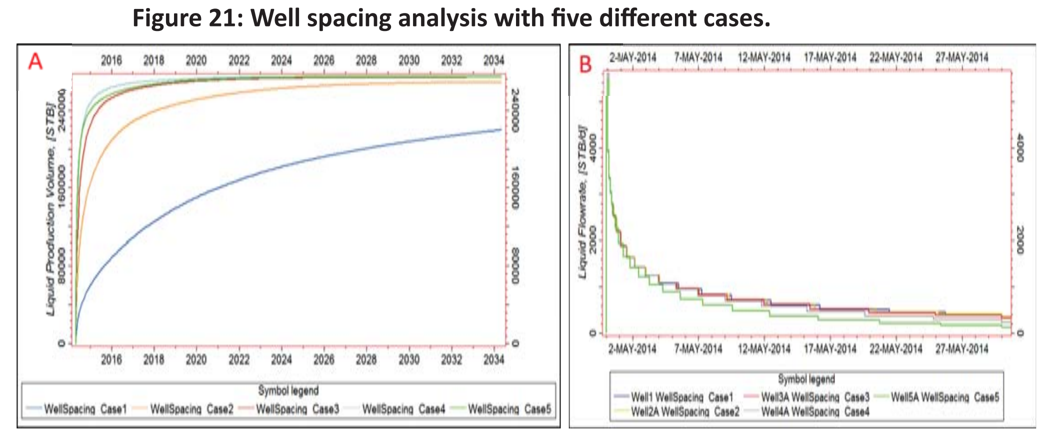


Figure 22: Well spacing analysis results for oil cumulative production (A) and oil production rate of a middle well in each case (B).

b/ Fracture spacing analysis:

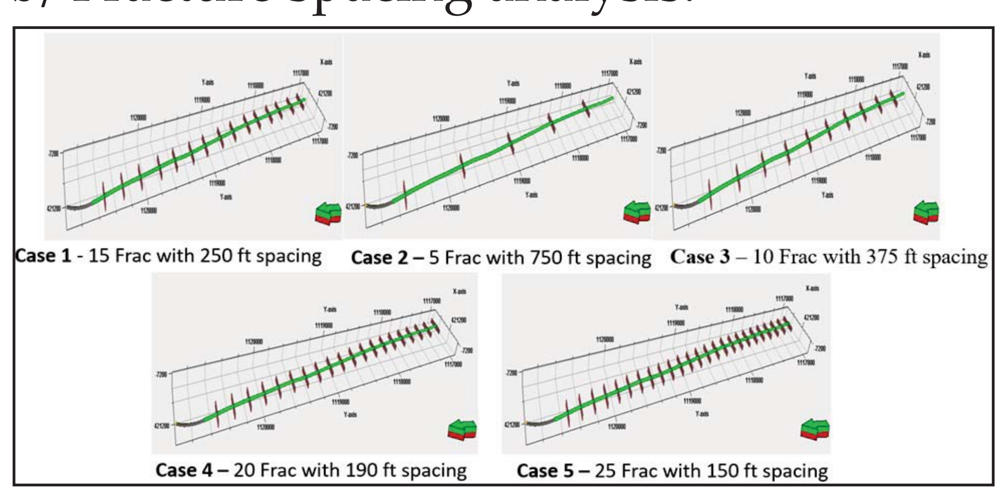


Figure 23: Fracture spacing analysis with 5 cases for different number of fracture stages and fracture spacing.

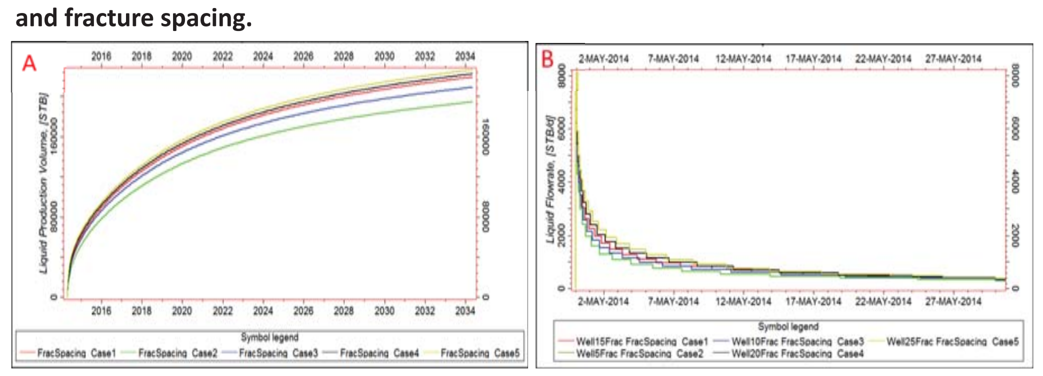


Figure 24: Fracture spacing analysis results for oil cumulative production and oil rate.

Results:

Field analysis provides optimum values for fracture spacing (Case 1) of 250 feet and well spacing (Case 3) of 440 feet between each well. The values were used for later model analysis.

2/ HIGH-RESOLUTION MODEL

Define characteristics of each facies that are present in the WCM into each model (50 ft x 50 ft x 5 ft).

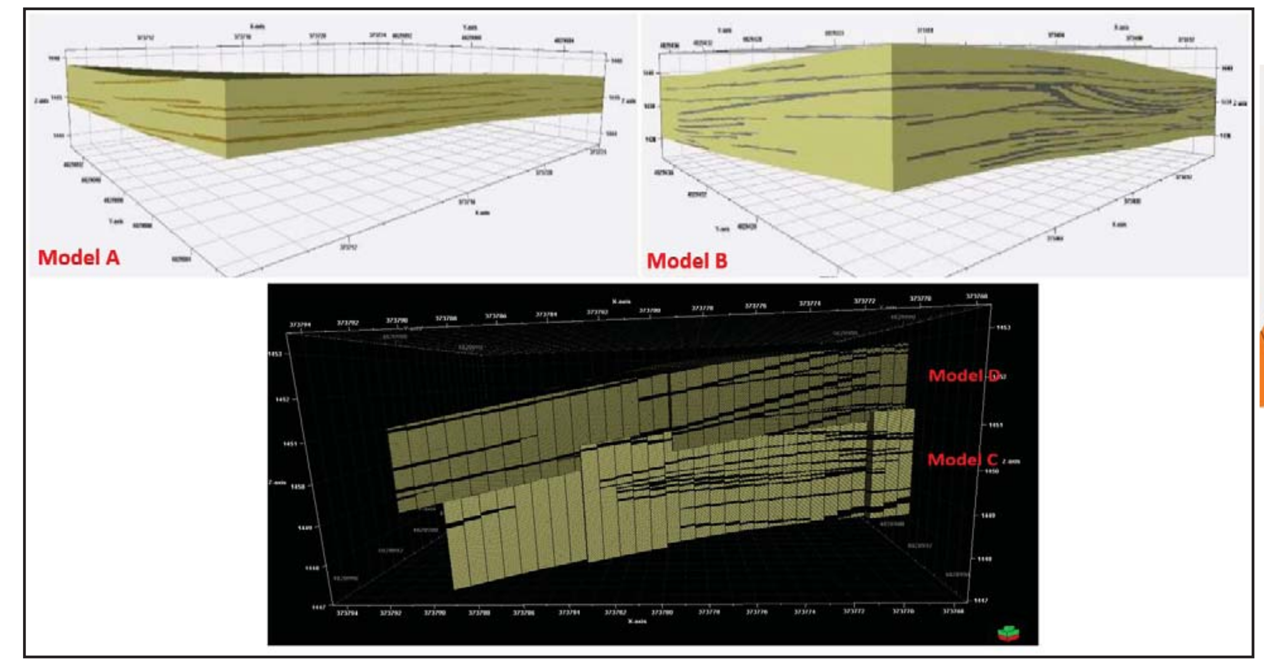


Figure 25: Four high-resolution models for thin, interbedded sandstone and siltstone/mudstone (Model A), shoreface parasequences (Model B), tidal bar base (Model C), and tidal bar top (Model D) facies.

Flow-based upscaling:

To capture the heterogeneities (cm-scale) of each facies into one coarser grid cell that may affects the flow at three different directions. Each mud drape is characterized by transmissibility multiplier.

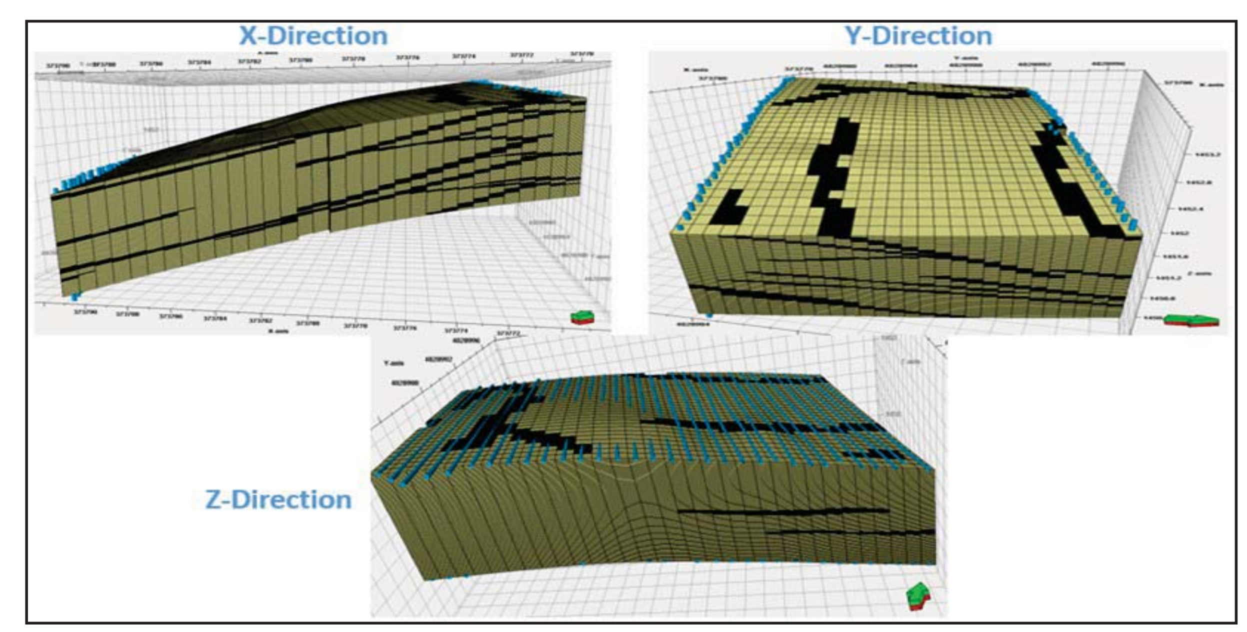


Figure 26: Examples of flow-based upscaling in three directions for tidal bar top model: Fluid is only allowed to flow in one direction for each simulation.

Table 2: Results of flow-based upscaling for each facies of Wall Creek Member with color code. (T_m = 0)

		Percentage of Permeability Reduction (Tm = 0)		
Color Code	Facies	X-Direction	Y-Direction	Z-Direction
Orange	Upper Tidal Bar	33.19	38.91	89.73
Grey	Lower Tidal Bar	15.48	13.66	66.05
Teal	Shoreface Parasequences	23.96	26.29	100
Yellow	Thin, interbedded sandstone and siltstone/mudstone	9.75	8.73	97.88
Red	Cross-bedded sandstone	N/A	N/A	N/A
Green	Parallel-laminated storm deposits	N/A	N/A	N/A

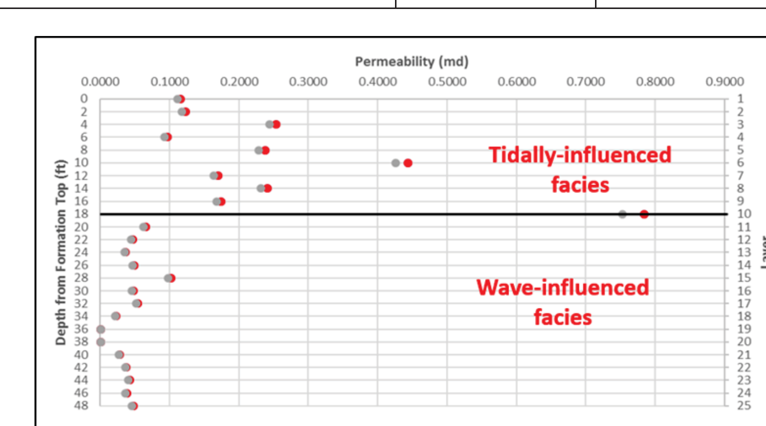


Figure 27: Permeability graph with boundary line between two distinct sedimentary facies.

3/ INTEGRATED OUTCROP MODEL

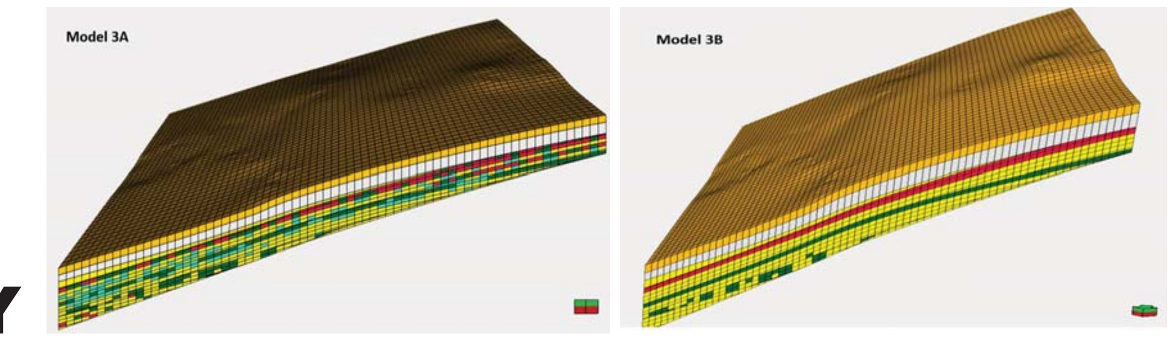


Figure 28: Integrated Outcrop Models: Geologic structural model (A) and Proxy structural model (B).

Field development analysis:

3 models: Base (geologic model), reduced (geologic structural model with T_m =0), and Proxy (proxy structural model).

1st: Effects of architectural controls

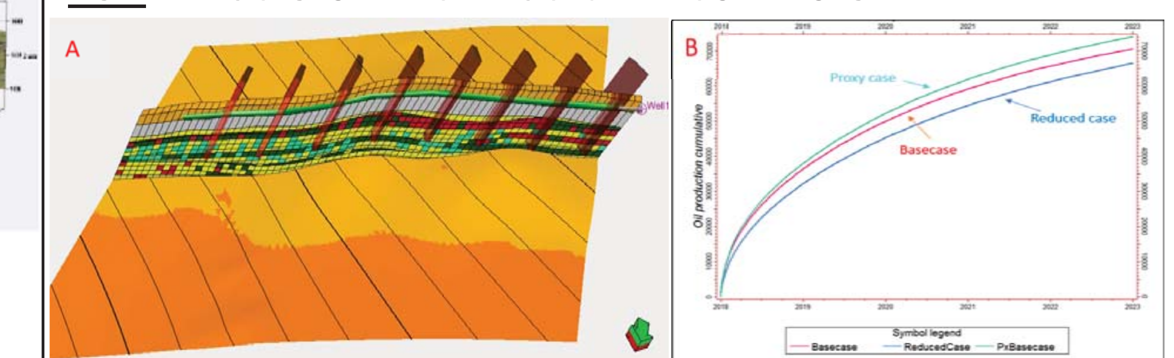


Figure 29: (A) Model with one horizontal well drilled into tidal bar facies. (B) Results of three model scenarios.

2nd: Effects of fractures height impact upward migration of water.

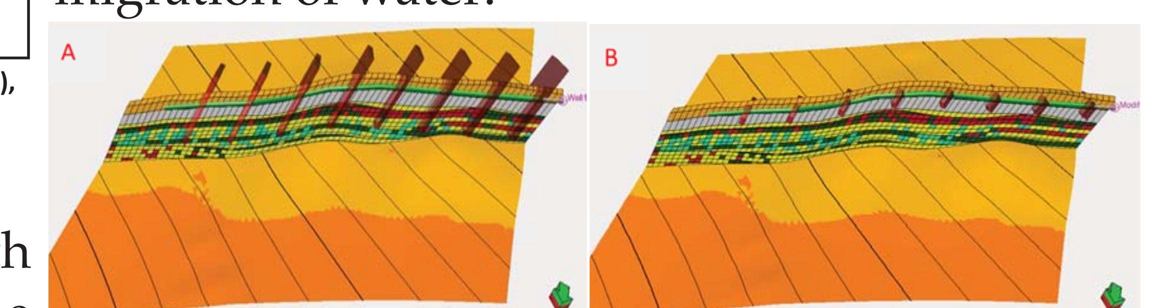


Figure 30: Models with a horizontal well drilled into tidal bar facies with (A) fractures penetrating entire model and (B) fractured penetrating tidal bar facies only.

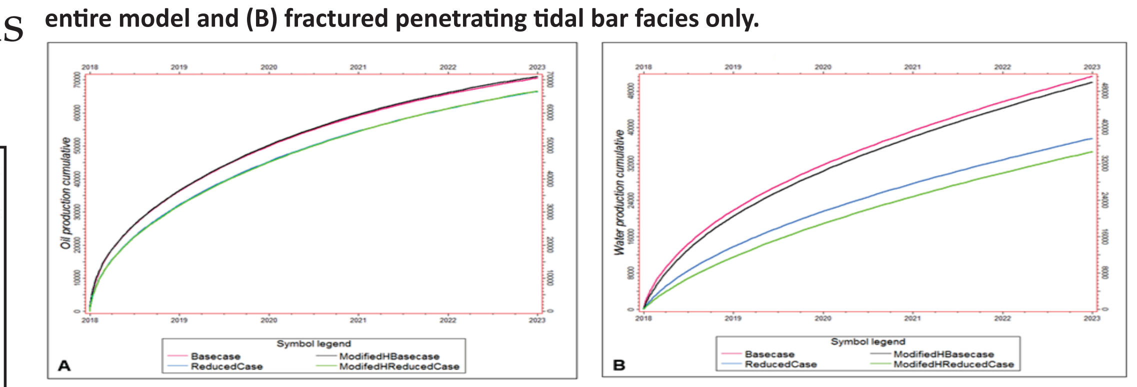


Figure 31: Results of (A) cumulative oil production and (B) cumulative water production for base and reduced cases with two different fracture heights.

3rd: Effects of architectural controls on well spacing analysis.

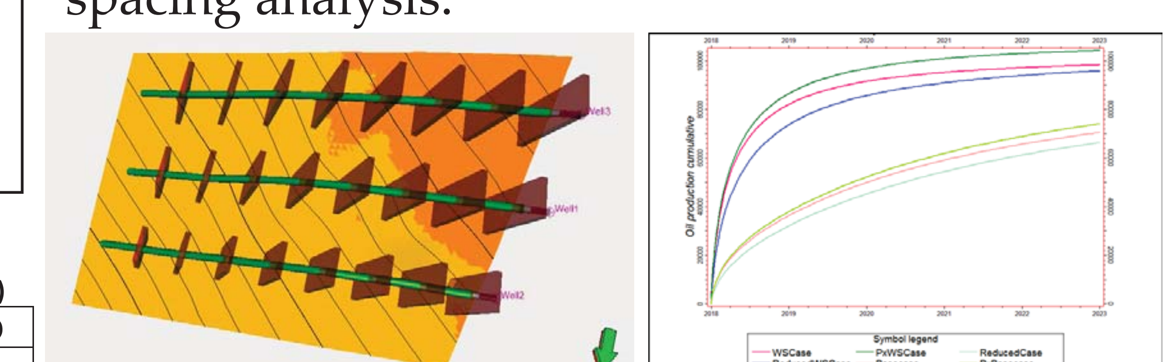


Figure 32: (A) Model with three horizontal well (440 ft spacing). (B) Results of three model scenarios.

CONCLUSION

- Successfully integrate the stratigraphic system from outcrop observation into reservoir model.
- Simplification and uncertainty from proxy model often overestimate the actual production.
- Wave-influenced facies contains high water saturation and should be avoided while drilling and completion.

REFERENCE

Le, Tuan, "INTEGRATED STRATIGRAPHIC CONTROLS FOR FLOW SIMULATION OF THE WALL CREEK MEMBER OF FRONTIER FORMATION: WESTERN POWDER RIVER BASIN, WYOMING" (2018). *Graduate Theses & Non-Theses*. 159. https://digitalcommons.mtech.edu/grad_rsch/159

SM ENERGY