Incremental Recovery Factor of at Least 9% can be Achieved Designing Optimum Inter-Well Distance Patterns on a 3-D Model for Polymer Flooding in Multilayer Fluvial Reservoirs*

F. T. Schein[1], J. Juri[1], M. Pacchy[1], A. M. Ruiz[1], M. Thill[1], P. Guillen[1], and V. Serrano[1]

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[1]YPF SA, Buenos Aires, Argentina (florencia.schein@ypf.com)

Abstract

It is widely accepted that there is an S-curve relationship between net-to-gross ratio and connectivity. However, at a given net-to-gross defined by the reservoir, connectivity rises steeply as well density increases. The aim of this work is to model different field development scenarios to estimate the optimum inter-well distance that maximizes ultimate recovery factor. A full understanding of the depositional context is critical for static model design and the key for an accurate estimation of the net-to-gross. As facies models tend to become complex seeking for accuracy when representing sedimentary architecture and heterogeneities, it is critical to consider that the gaps in the geological record and the presence of uncharacterized high permeability facies (“thief-zones”) can become the essential features controlling fluid transport connectivity. Several patterns at a wide range of inter-well distances have been designed to evaluate static connectivity variation for every given scenario. Our history matched simulations of polymer flooding at different scales and resolutions indicate that at least 7% incremental recovery can be achieved by infill drilling. The estimation of the resulting increment has the limitation that the geological features of the 30-acres model find it is based on the background of a conceptual geological model designed at 10 acres. This is, however a reason to believe the estimation is still conservative.

Dynamic simulations of the 3D models and polymer tracers allowed us to identify the “sweet spots” within the reservoir necessary to reach pattern confinement aiming to maximize the reservoir sweep efficiency at an optimal inter-well distance, achieving a 7% increment in ultimate recovery factor when taking infill drilling from 30 to 10 acres. A thorough environmental representation combined with full field data simulation provide a valuable insight into fluid dynamics in the reservoir, connectivity and injection patterns. Using this model for monitoring guidance and feeding the model with field data becomes a powerful resource for injection management and designing the most suitable full field polymer implementation strategy considering logistics, monitoring and operational constraints.

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AAPG ICE 2019
International Conference & Exhibition
AAPG
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Buenos Aires,
Argentina

01 Background

- Grimbeek Field
- Reservoir Features
- Production History

02 Model

- Conceptual Model
- Connectivity vs NTG
- Forecast vs Results

03 Full Field Analysis

- Sweep efficiency vs Inter-well distance
- Scenarios Evaluation

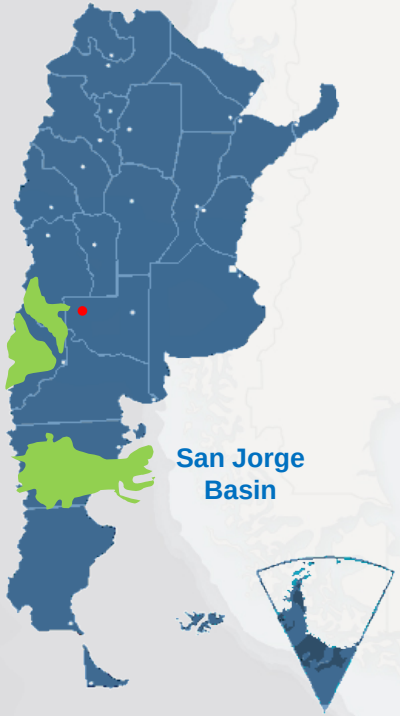
04 Results

- Strategy Recommendations

05 Conclusions

- General Considerations
- Final thoughts

01- THE FIELD



EOR Strategy: Polymer

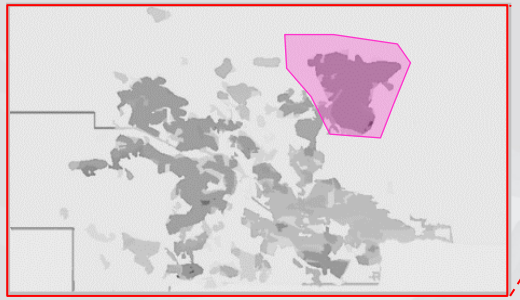
STOOIP

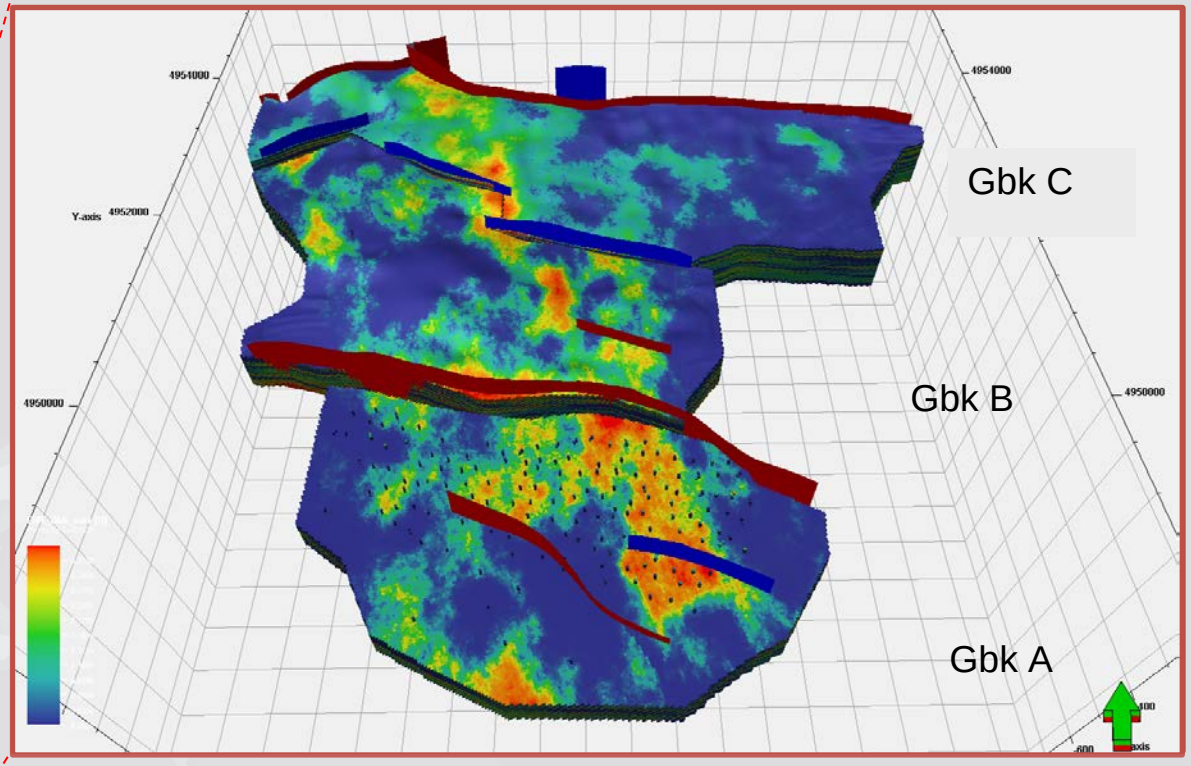
42 Mm3

(Fm. El Trébol)

Permeability
>1D
Viscosity
120 cp
T°
60°C

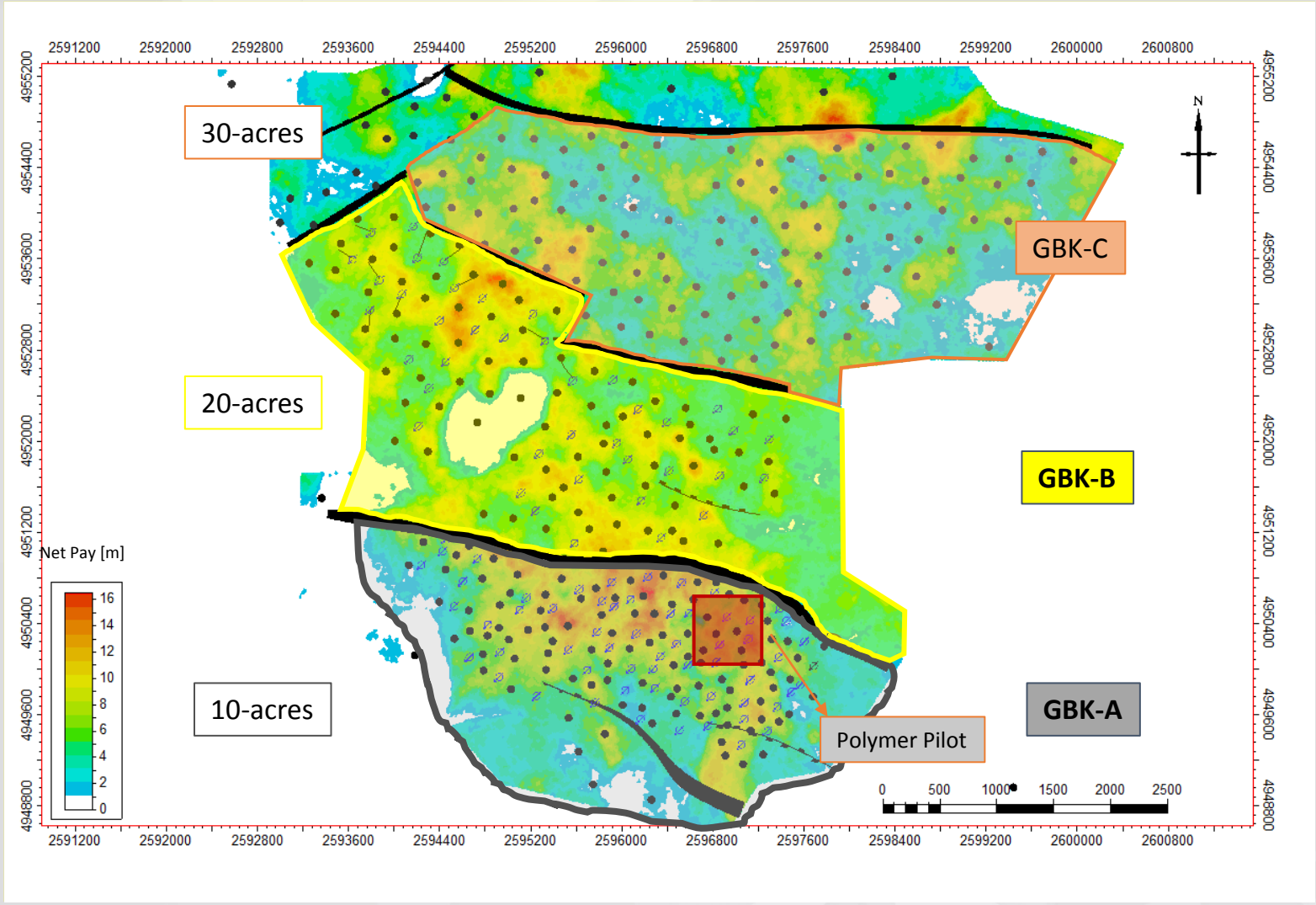
Manantiales Behr

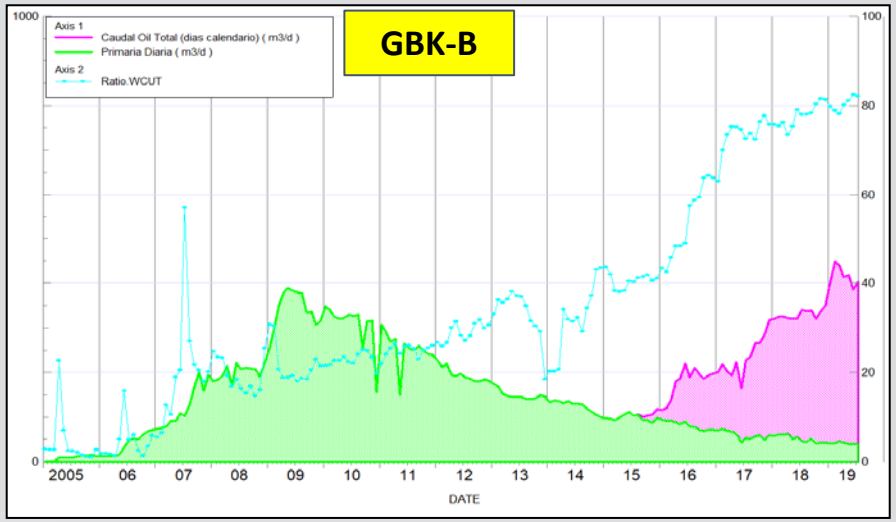


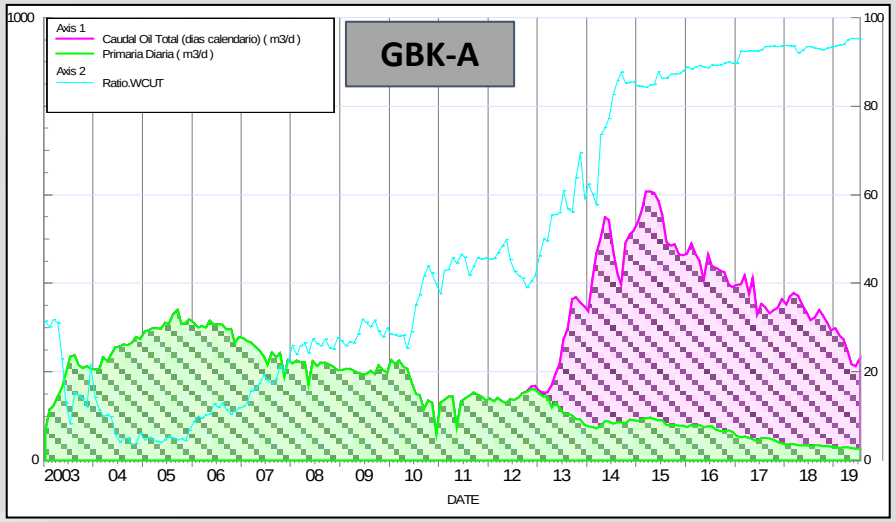


Gbk_A (10acres)	Primary 2002	WF 2010	PF (pilot) 2015
Gbk_B (20acres)	Primary 2007	WF 2014-18	PF 2020+
Gbk_C (30acres)	Primary 2010	WF/PF 2021+	

01- PRODUCTION HISTORY



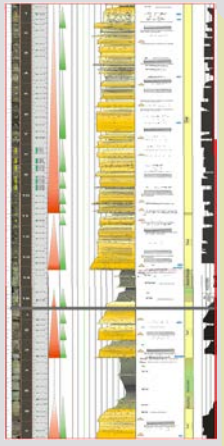




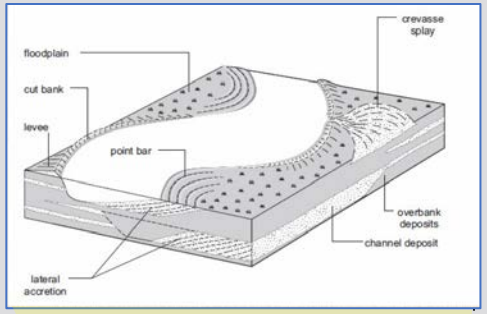
01 – RESERVOIR FEATURES

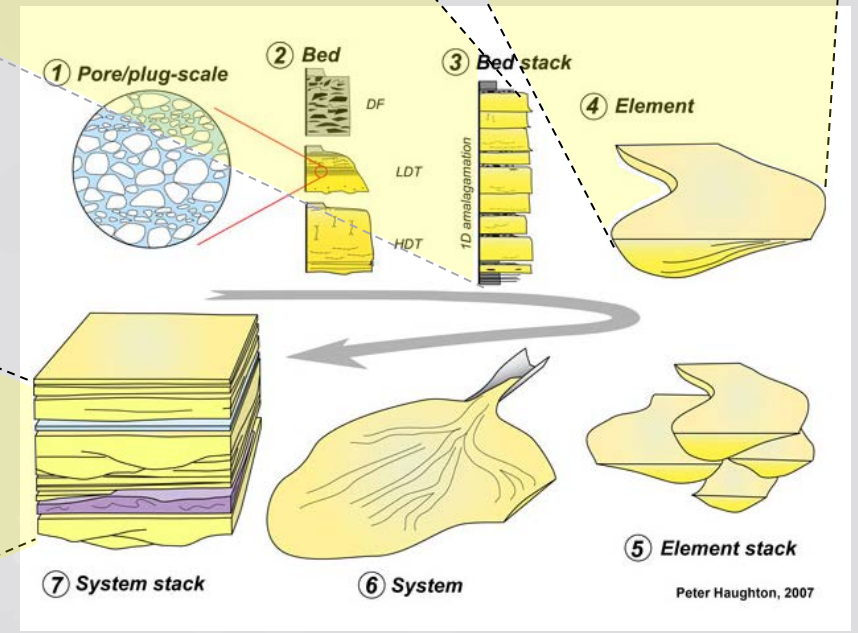
- Mixed load channel belt deposits from meandering river systems
- Complex internal architecture
  - ✓ stacked depositional features
  - ✓ scoured basal contacts
  - ✓ channel and bedform migration (range of scales)
- Strong reworking in the centre of meanders belts
- Many bounding surfaces and disturbed deposits

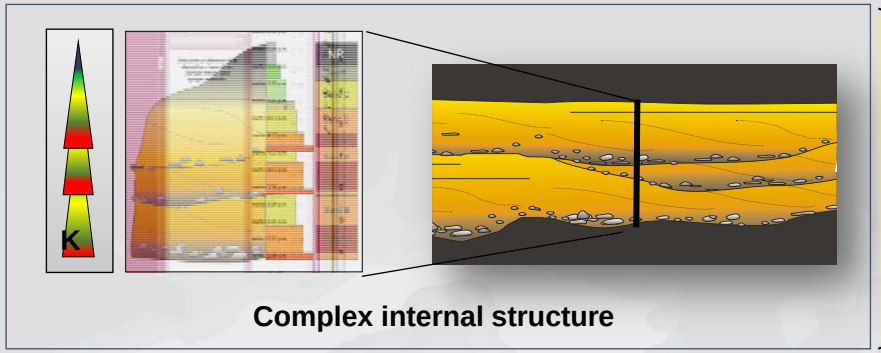
Gbk-981



Single Channel





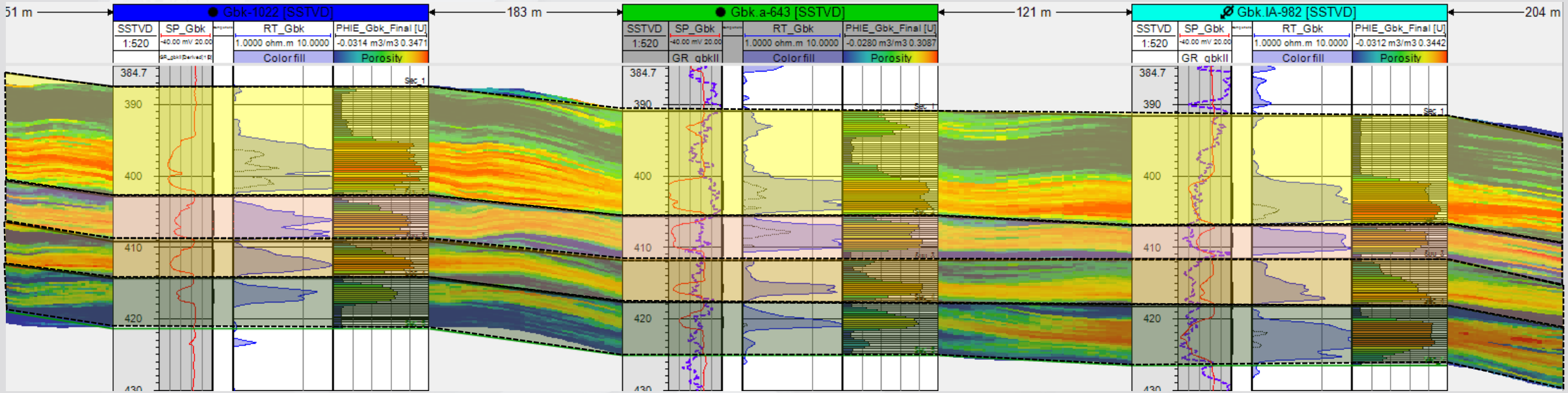


Complex internal structure

02- MODEL DESIGN

CONSIDERATIONS & CONSTRAINTS

- **Simple Correlation** : Sequence-defined correlation, horizontal layering
- **Petrophysical Model** : Maximize representation of channel heterogeneities
- **Reservoir Connectivity** guided by field-based data of water-flooding response
- **Flow barriers** Modelling



02- CONCEPTUAL MODEL

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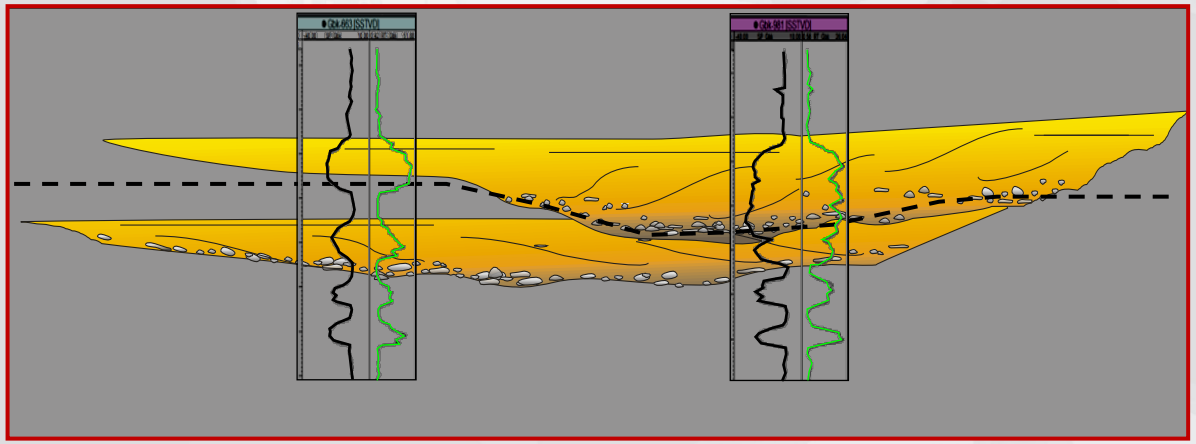
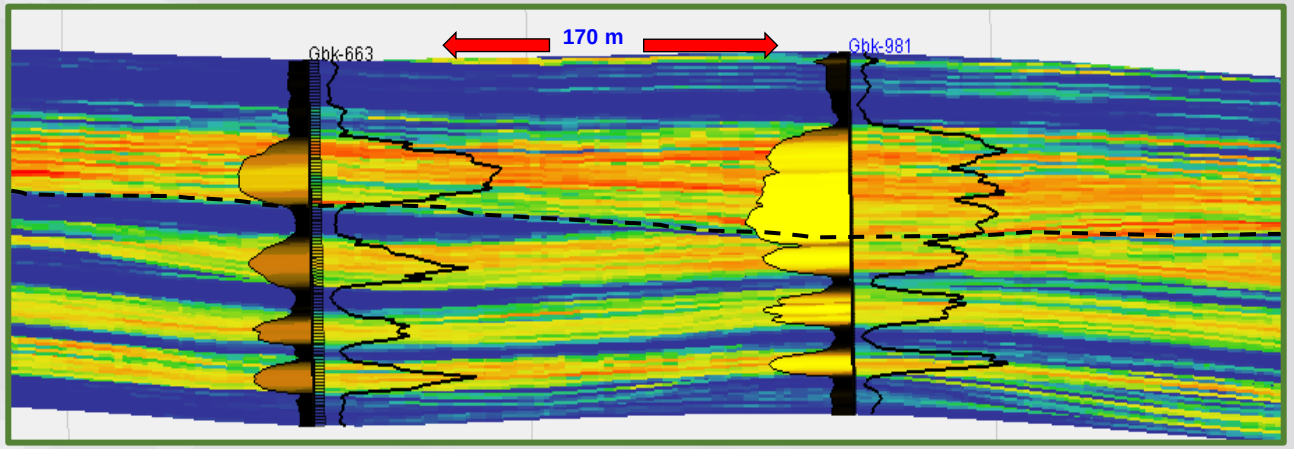
CONCEPT



MODEL



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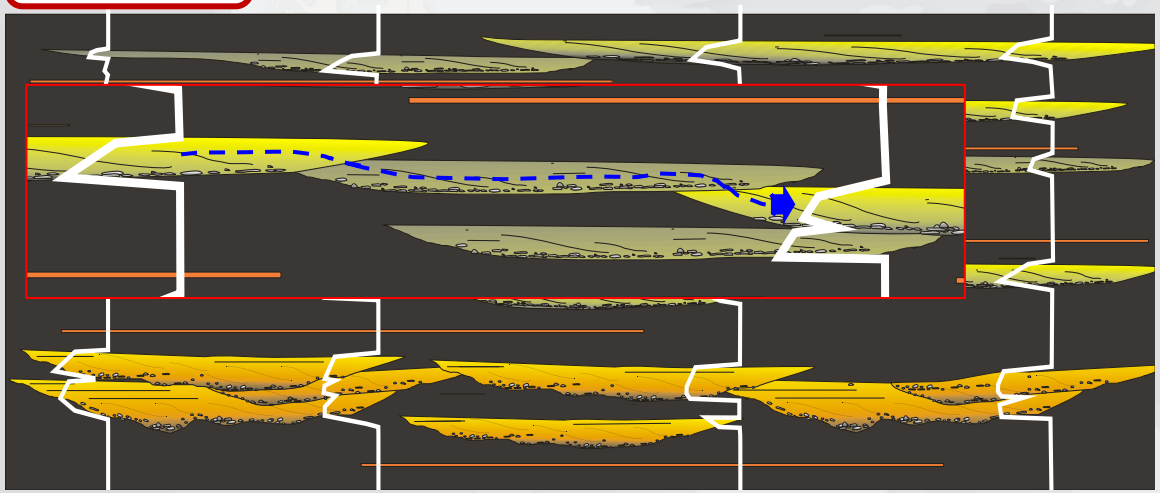

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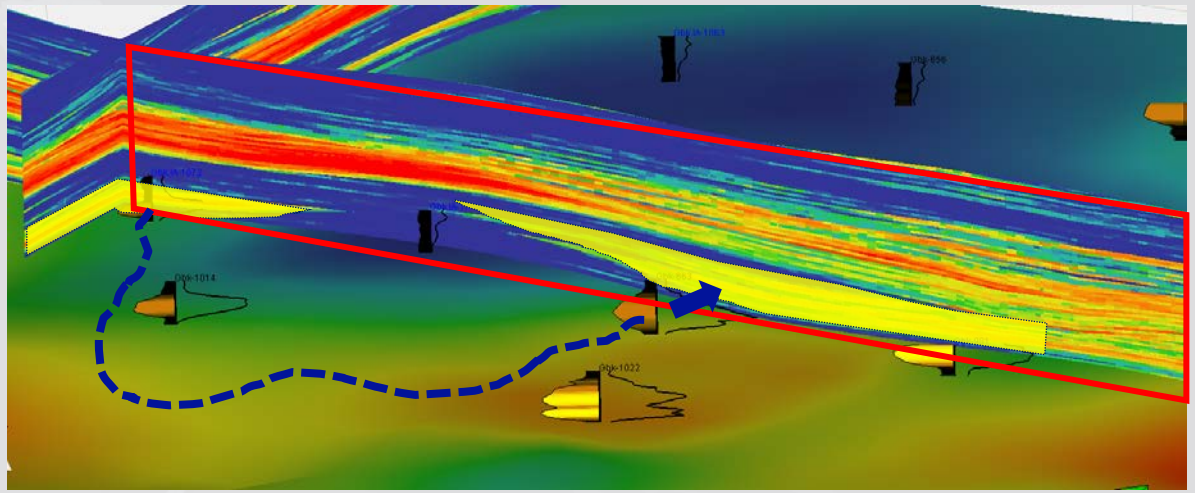

02- CONNECTIVITY VS NTG

CONSIDERATIONS & CONSTRAINTS

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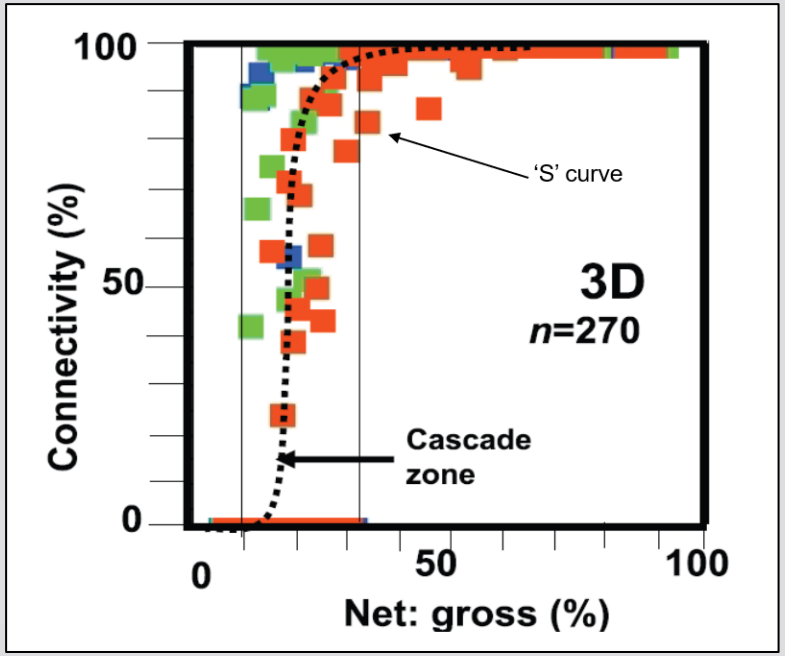
- **Petrophysical Model** : Maximize representation of channel heterogeneities
- **Reservoir Connectivity** guided by field-based data of water-flooding response
- **Flow barriers** Modelling

CONNECTIVITY

- Strongly influenced by heterogeneities modelling
- Clear relationship between NTG and connectivity – Analysed using percolation theory (*Larue&Hovadik*)
- S-shaped graph based on 270 different Boolean models of channels using a wide variety of channel characteristics and simulations

At a given NTG (~50%) connectivity rises steeply as well density increases



Larue & Hovadik, 2006. Connectivity of channelised reservoirs: a modelling approach. Petroleum Geoscience, Vol. 12 2006, pp. 291-308

In 3D models percolation threshold for a variety of shapes is

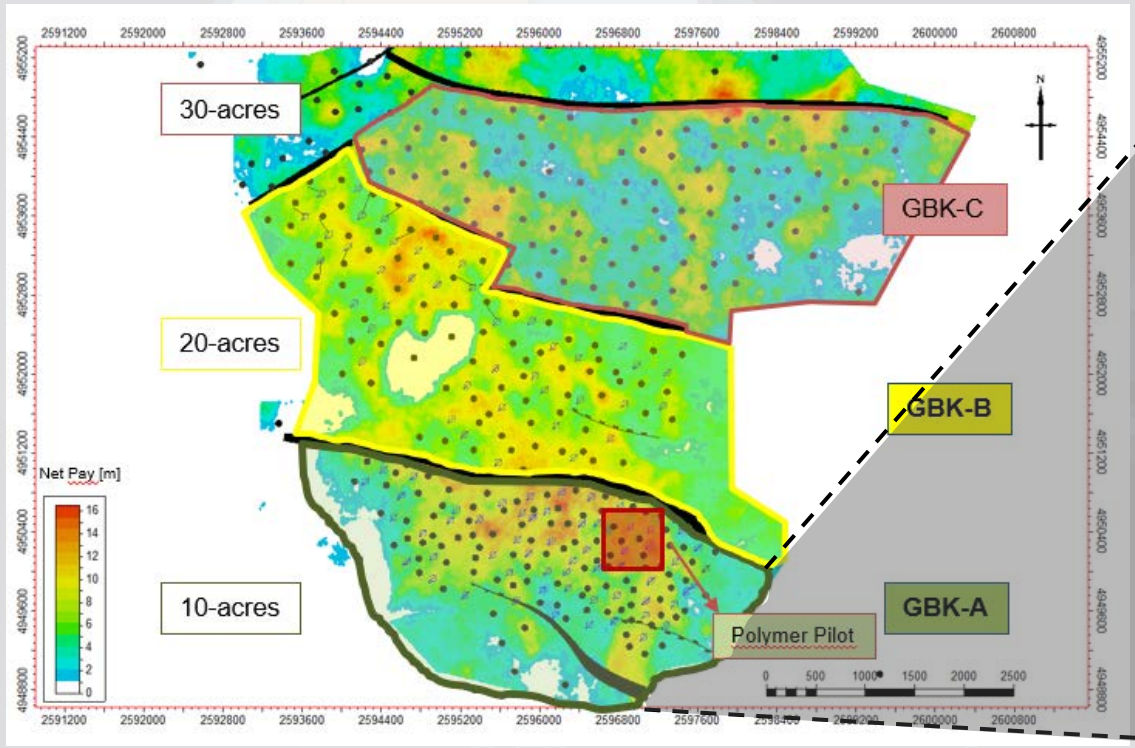
<20% low connectivity

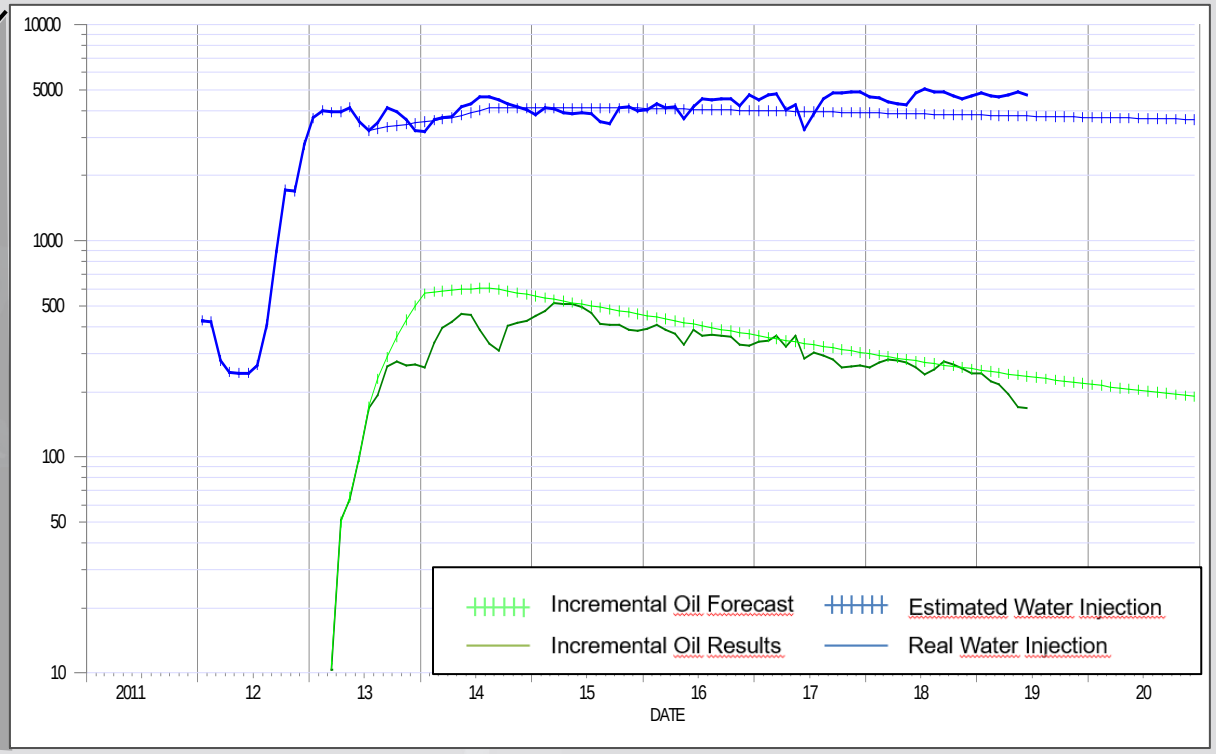
>30% NTG reservoir is highly connected

10%-30% NTG can result in 100% or 0% connectivity (Cascade zone)

02- FORECAST VS RESULTS

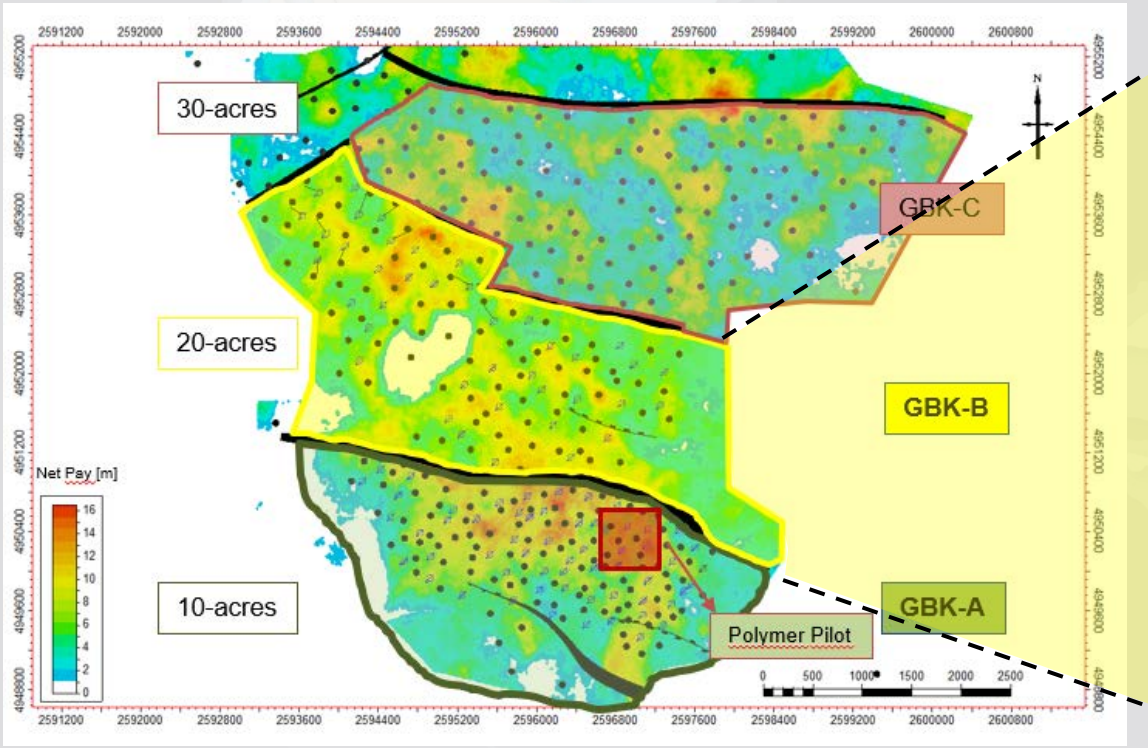
GBK A: Waterflooding

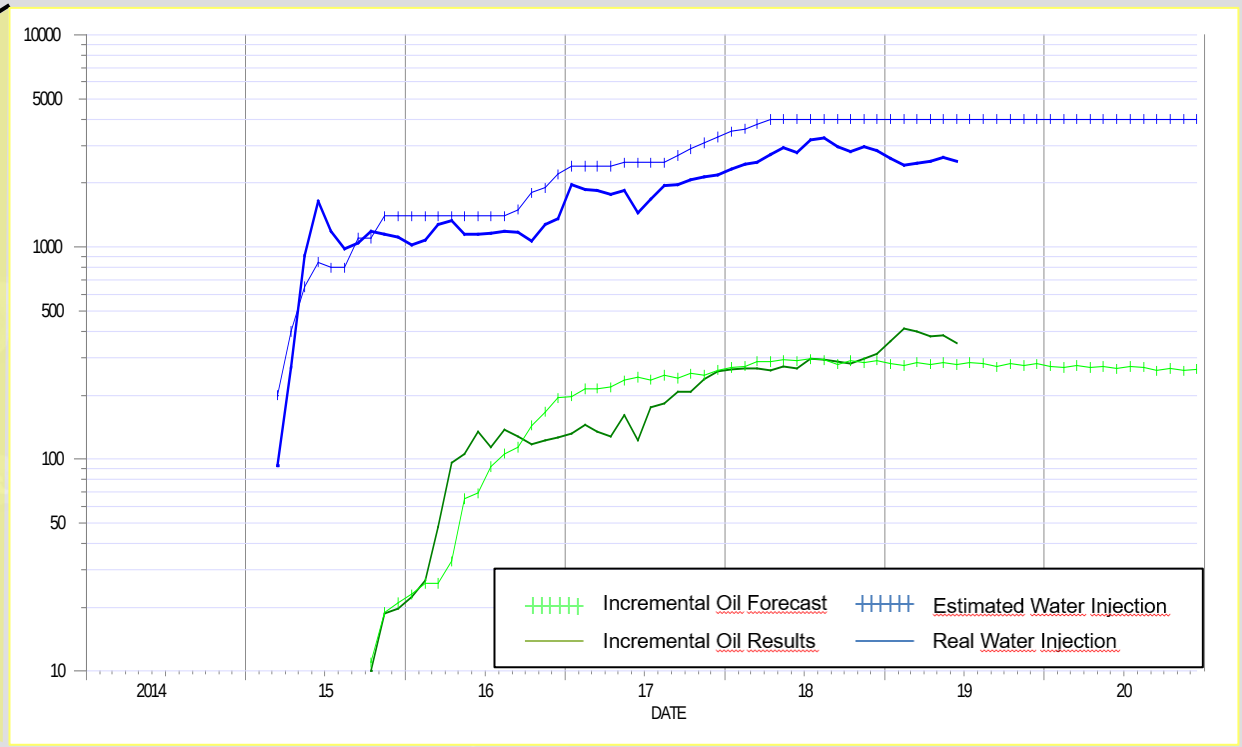




02- FORECAST VS RESULTS

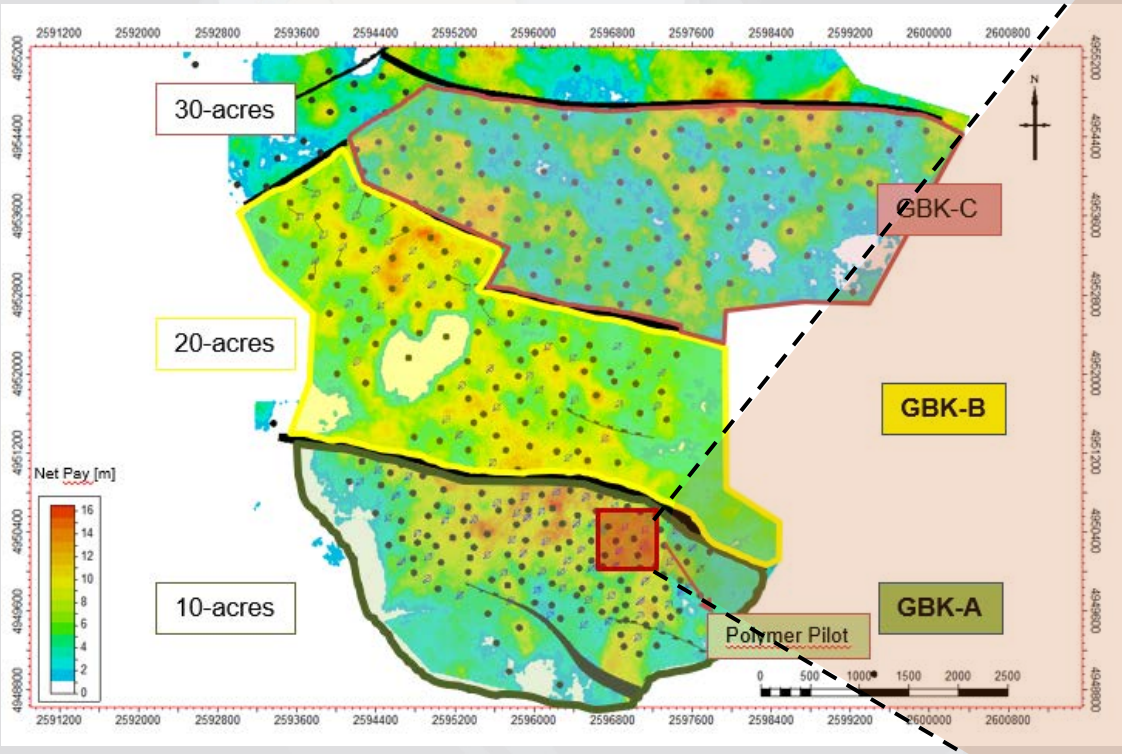
GBK B: Waterflooding

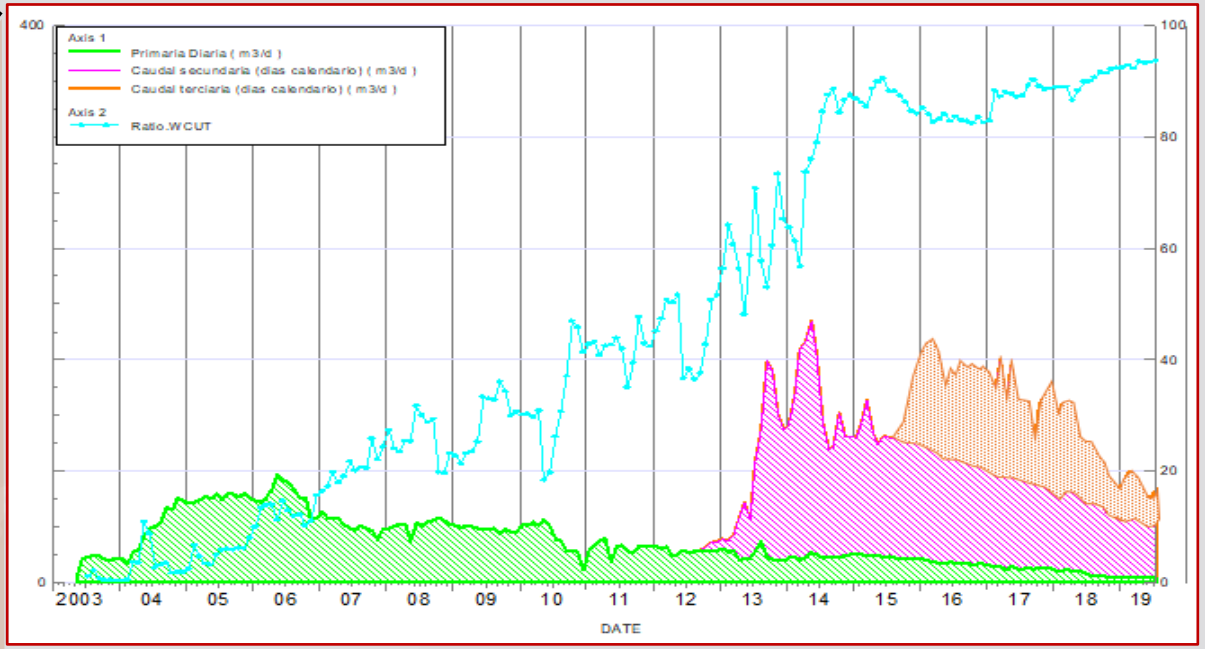


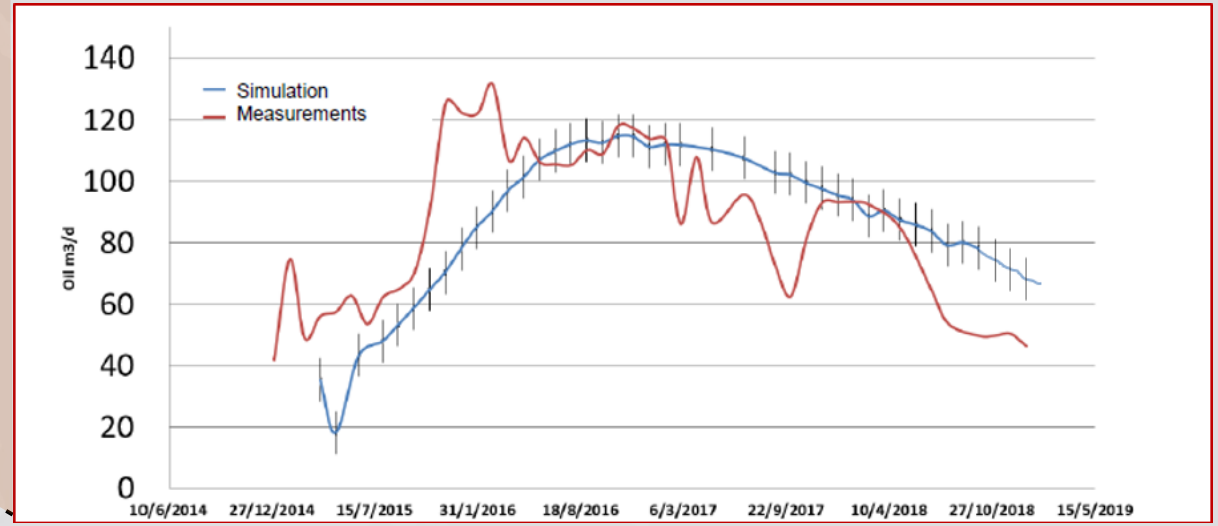


02- FORECAST VS RESULTS

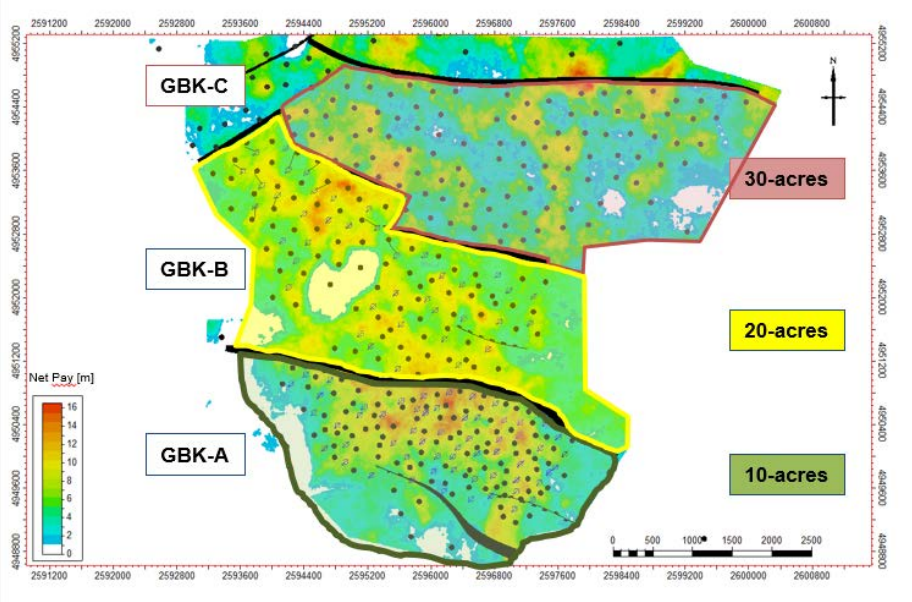
GBK A Pilot: Polymerflooding







03 – FULL FIELD ANALYSIS



$$RF(PF) = \frac{STOOIP - OIP\_final(PF)}{STOOIP}$$

RF(PF) = Recovery Factor (polymerflooding)
OIP_final(PF) = Oil in place @ end of Polymerflooding Strategy

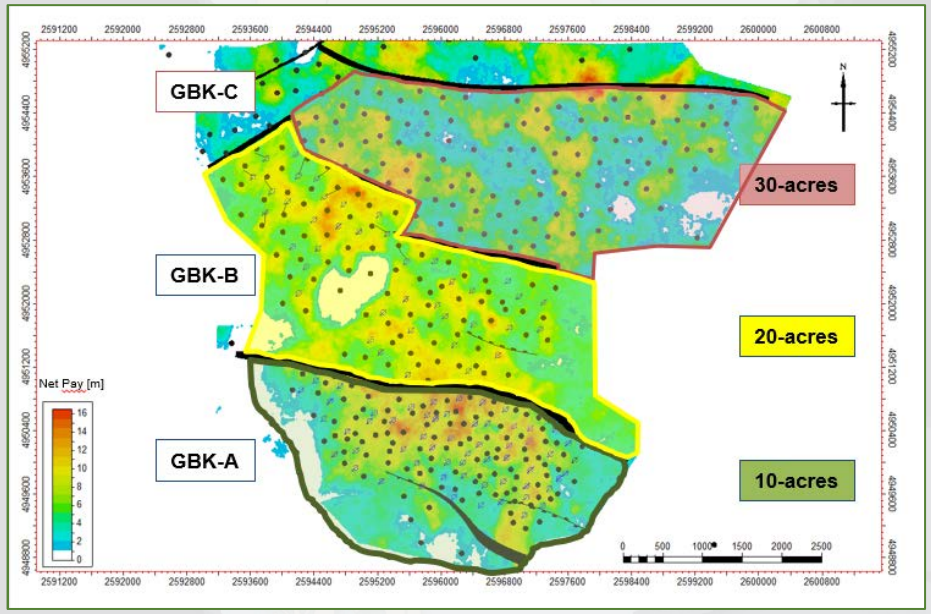
- RF **Waterflooding** ✓
- RF **Polymerflooding** (Pilot) ✓

RF = Volumetric Efficiency (Ev) * Displacement Efficiency (Ed)

$$Ev = \frac{\text{Connected Pore Volume}}{\text{Pore Volume}}$$

$$Ed = \frac{Soi - Sof}{Soi}$$

03 – SWEEP EFFICIENCY VS INTERWELL DISTANCE



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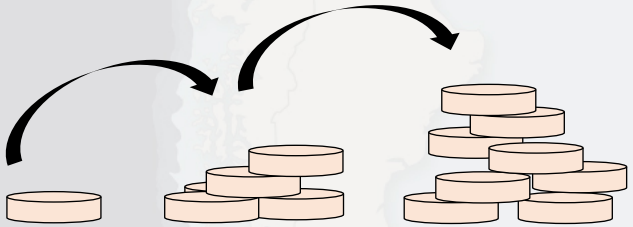
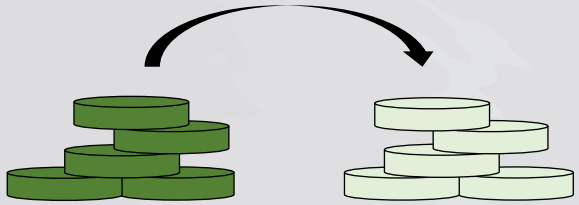
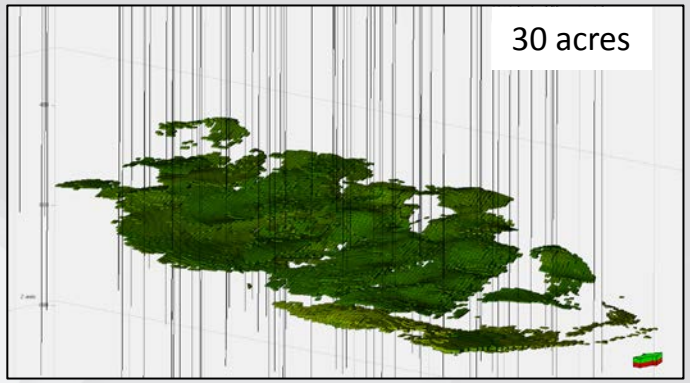


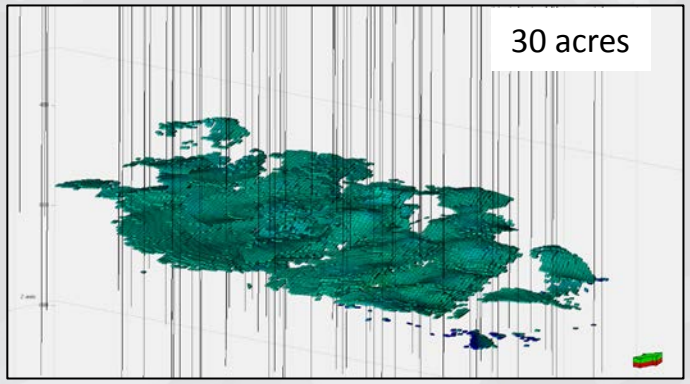
$$Ed = \frac{Soi - Sof}{Soi}$$



Connected pore volume

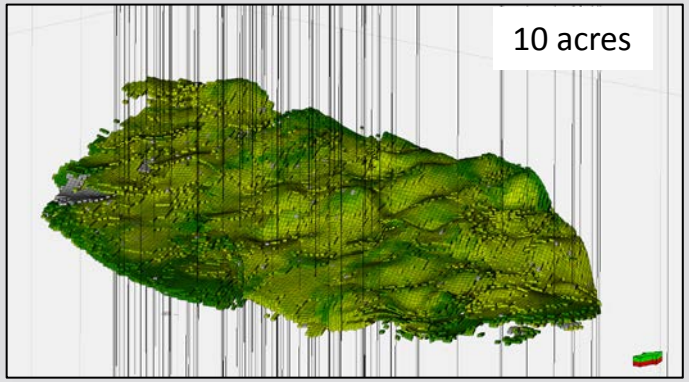


Sweeped oil



9 - 15%

Connected pore volume



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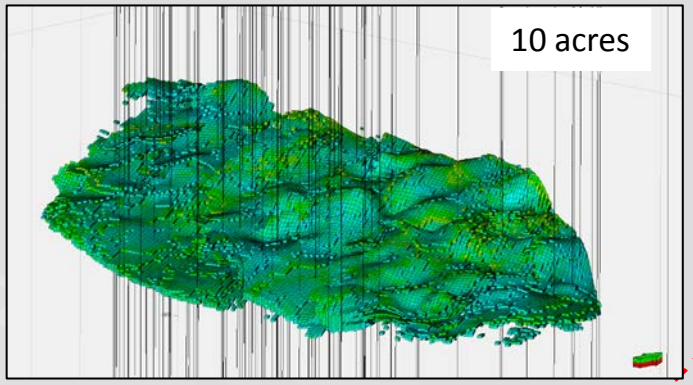
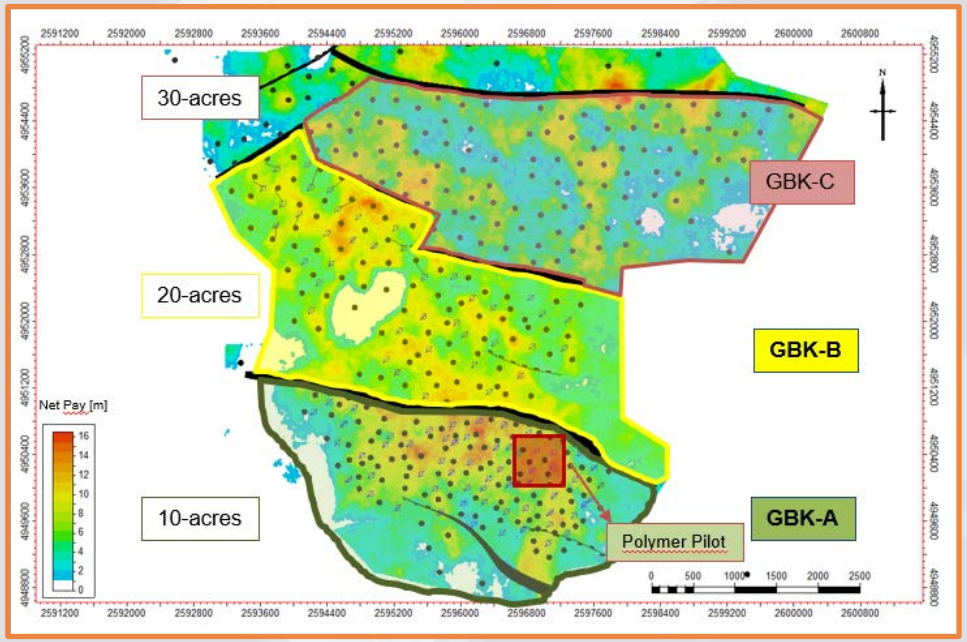


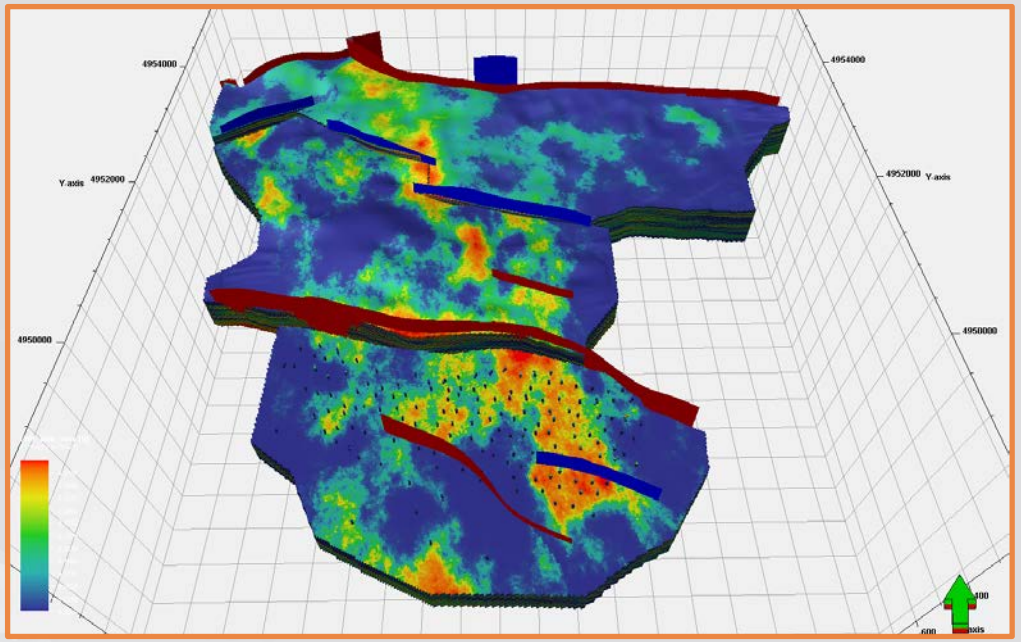
03- FORWARD MODELLING

Actual patterns



- Reservoir features ✓
- Pattern desing criteria ✓
- Inter well distance ✗

Field Model



- Model features and constraints ✓
- Time Interval and recovery strategy ✓
- Inter well distance ✗

03- FORWARD MODELLING

9 - 15%

4 - 7%

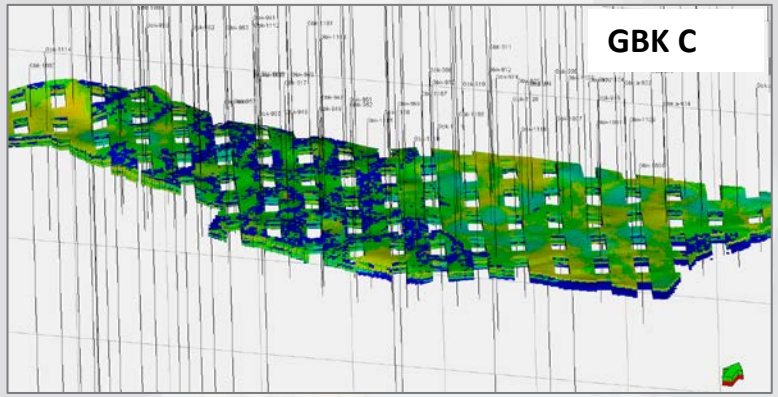
5 - 8%

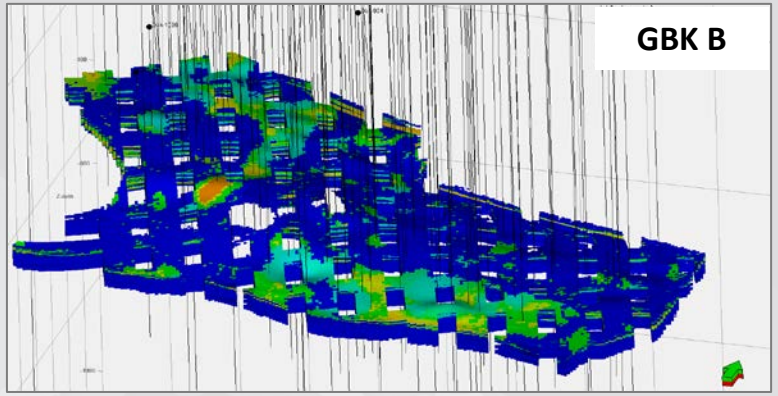
~30 acres

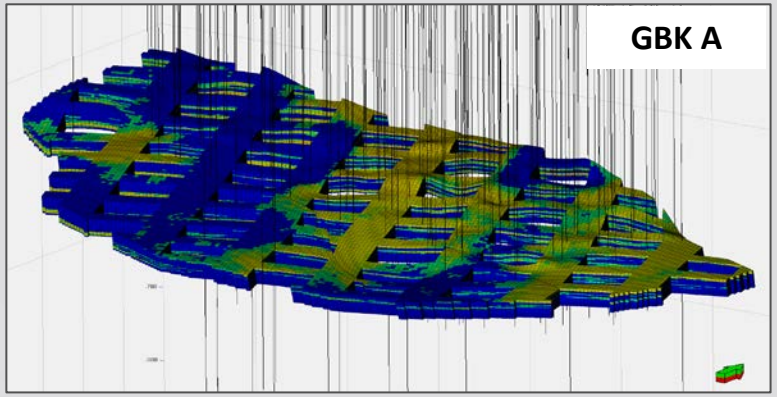
~20 acres

~10 acres

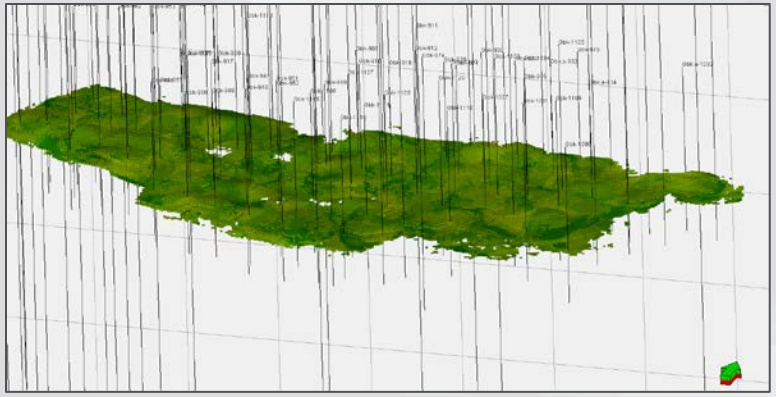
Final Sw

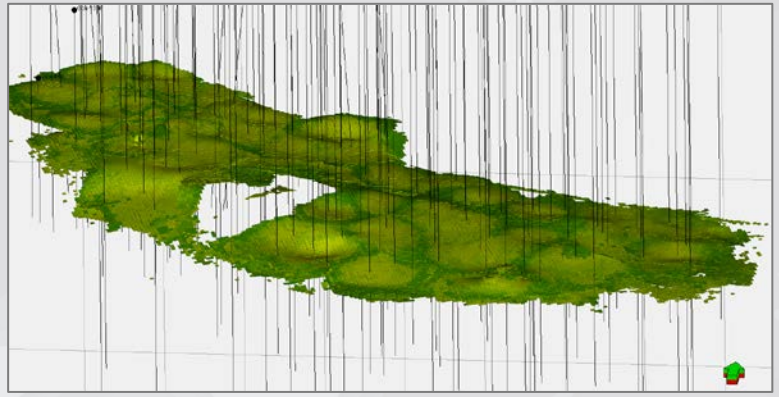


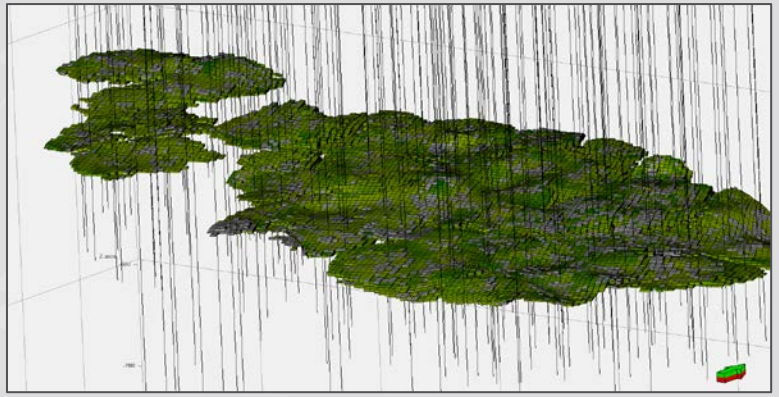




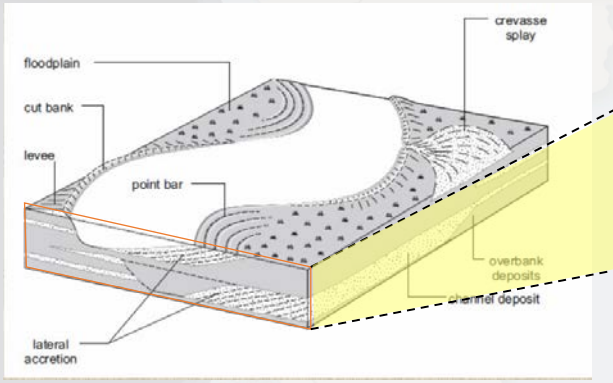
Recovered Oil



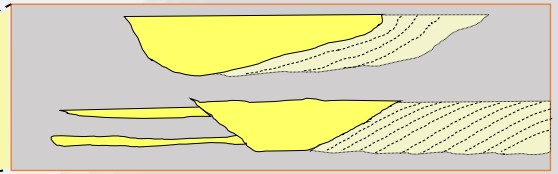




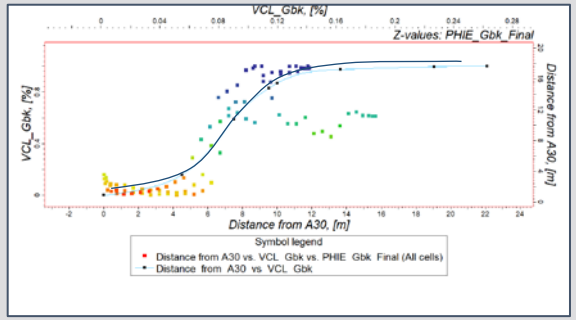
03- SCENARIO ANALYSIS: SINGLE CHANNEL



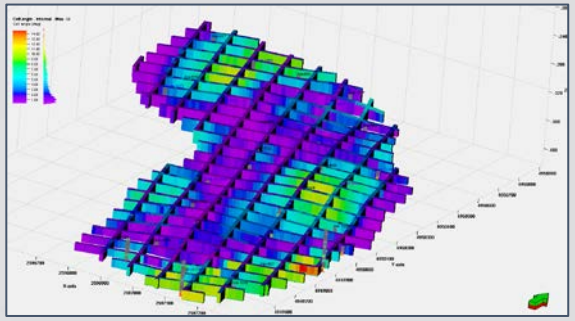
Point Bar – lateral accretion deposits

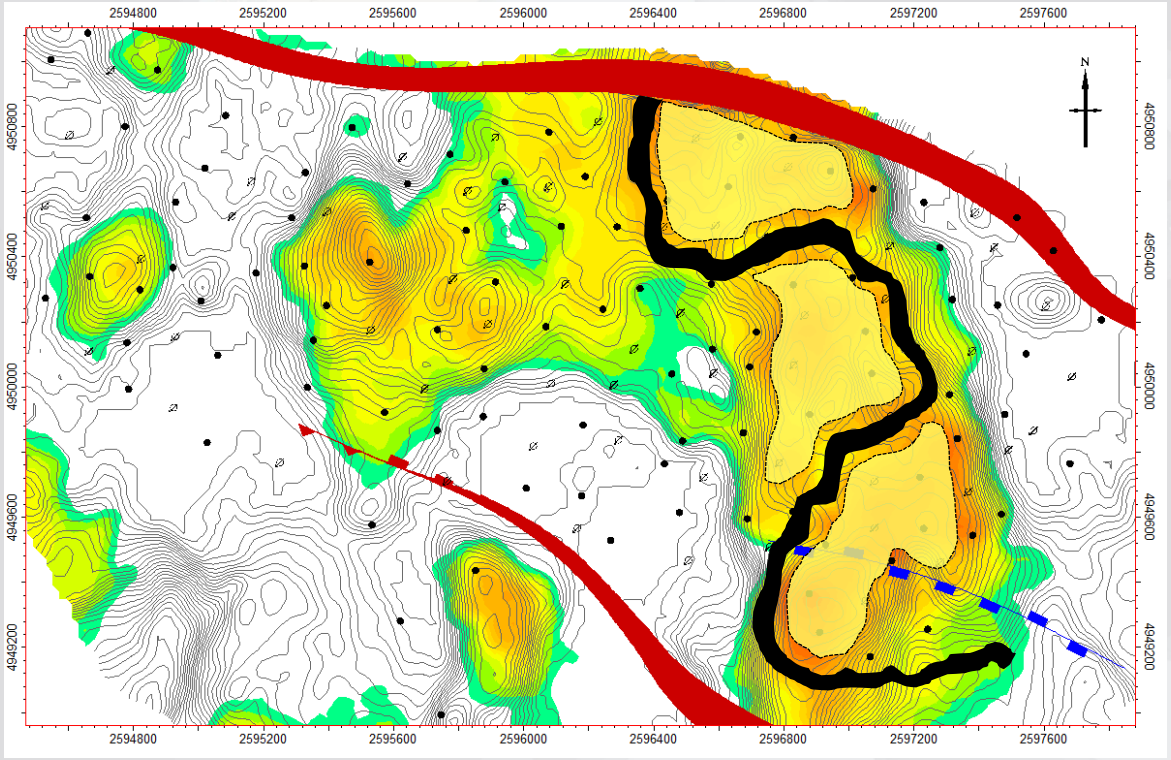


Property populationTrend

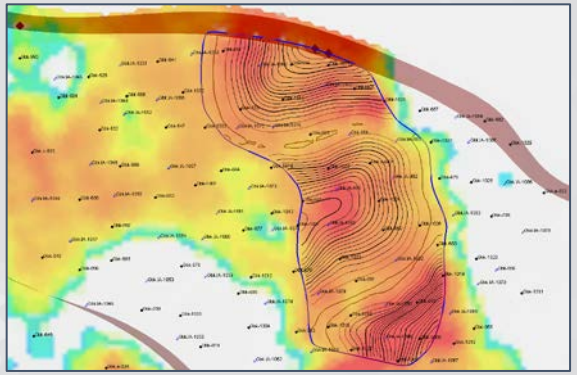


Cell angle Grid → **Channel shaped layering**



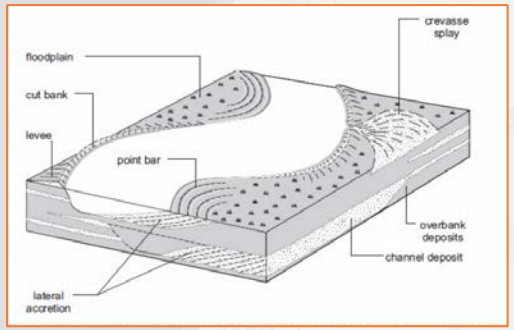


Depositional Surface

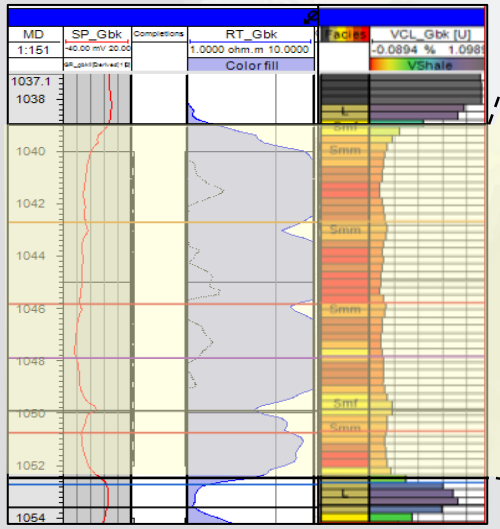


03- SCENARIO ANALYSIS: MULTIPLE CHANNEL

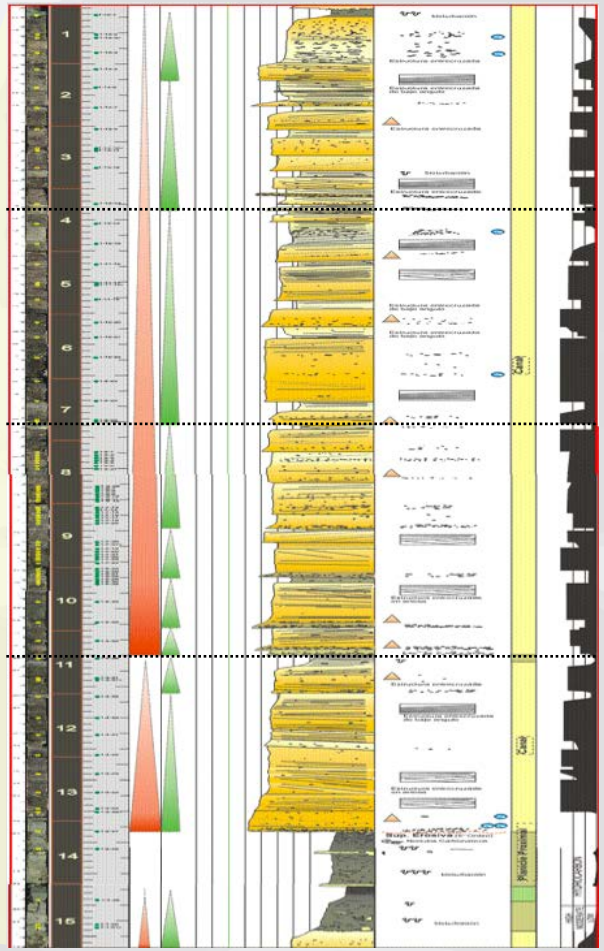
Single Channel Model



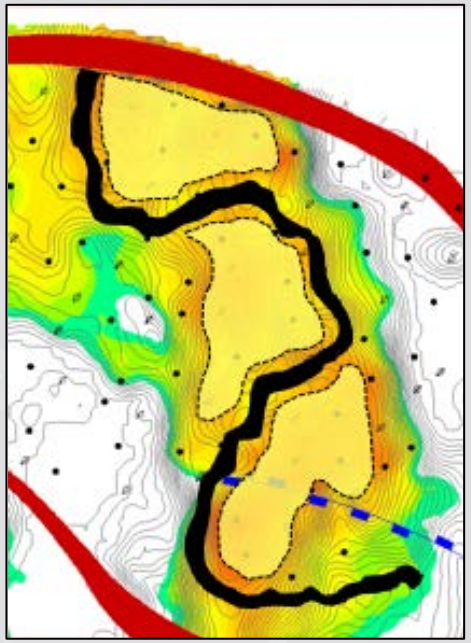
Sequence Correlation



Well Core

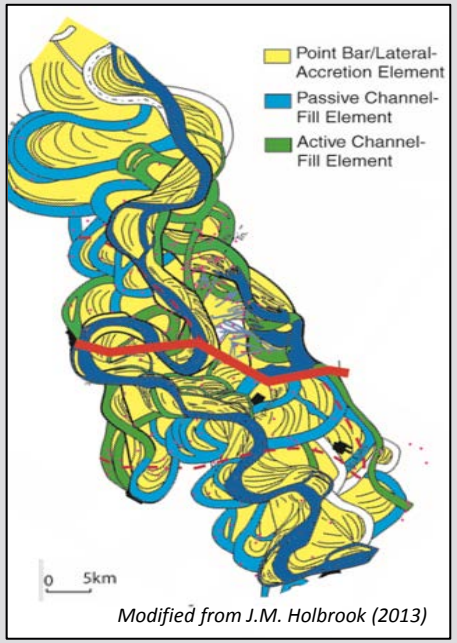


CONCEPT -1



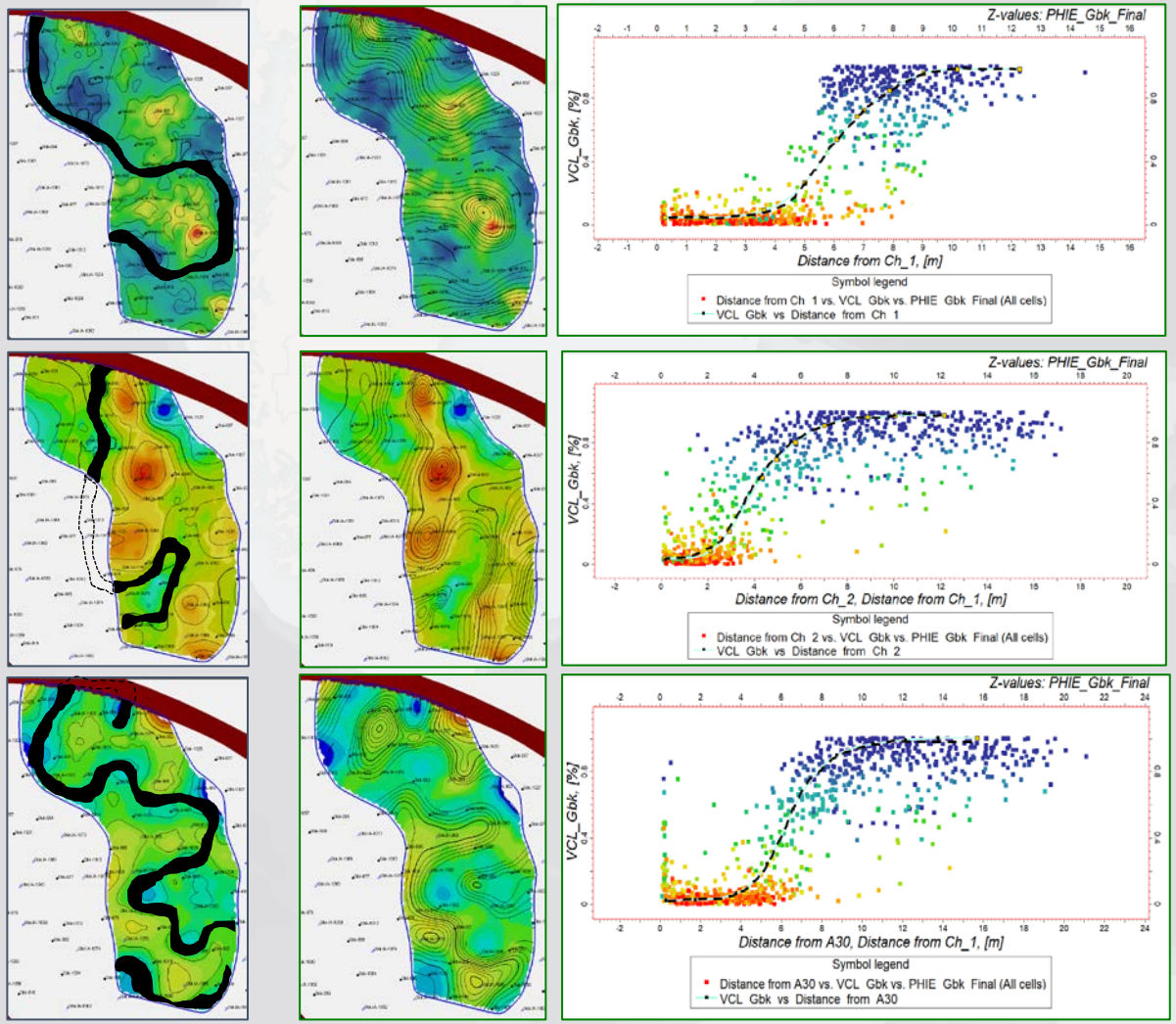
Single Channel

CONCEPT -2

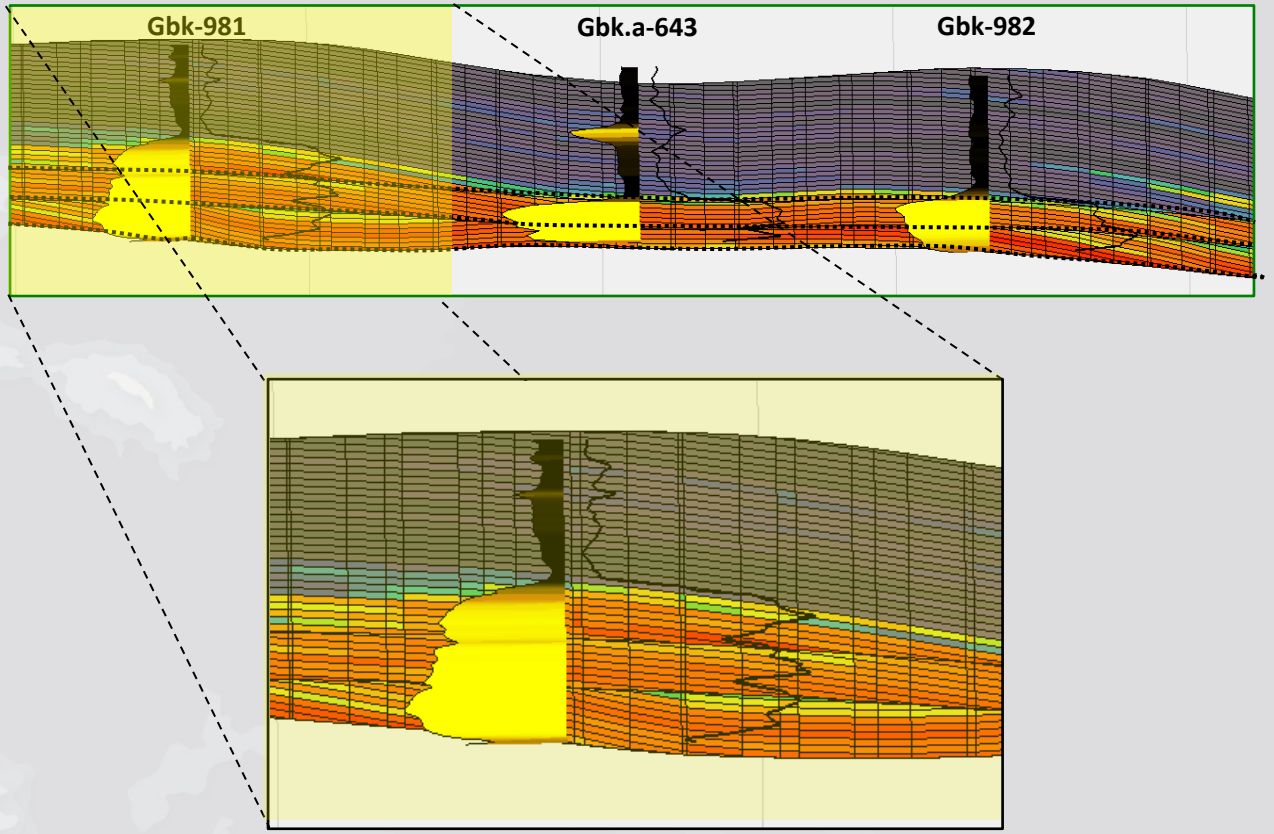


Multiple Channel

03- SCENARIO ANALYSIS: MULTIPLE CHANNEL

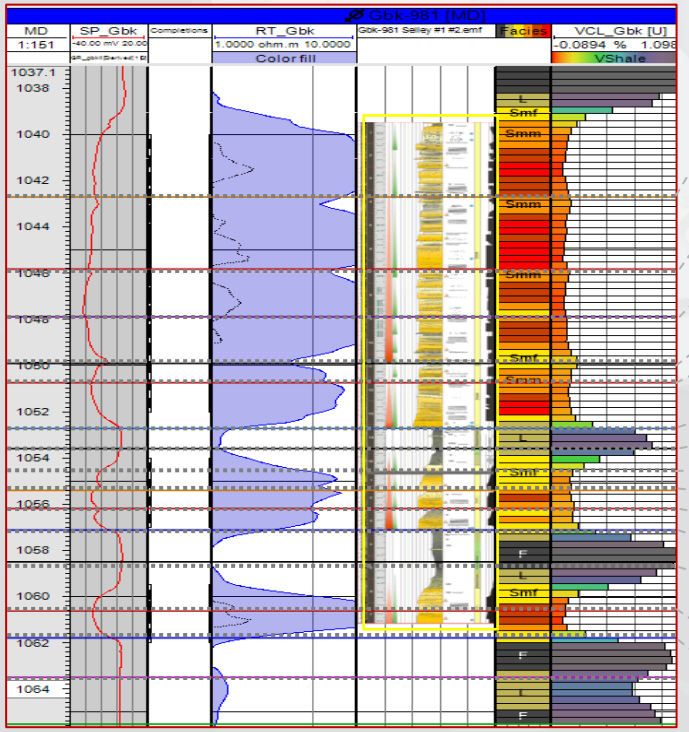


- Complex correlation: “individual” elements
- Channel geometry layering for each element

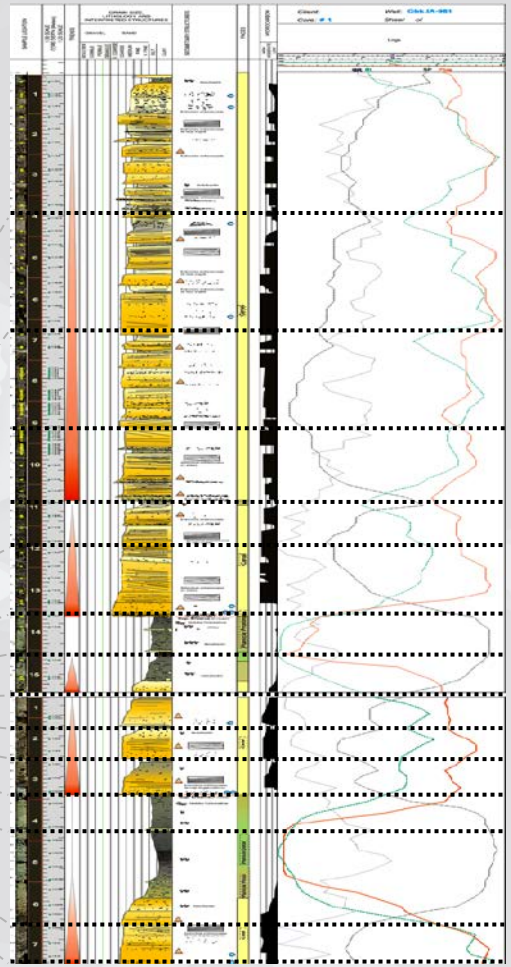


03- SCENARIO ANALYSIS: COMPLEX - HORIZONTAL LAYERING

- Maximum detail correlation
- Horizontal Layering

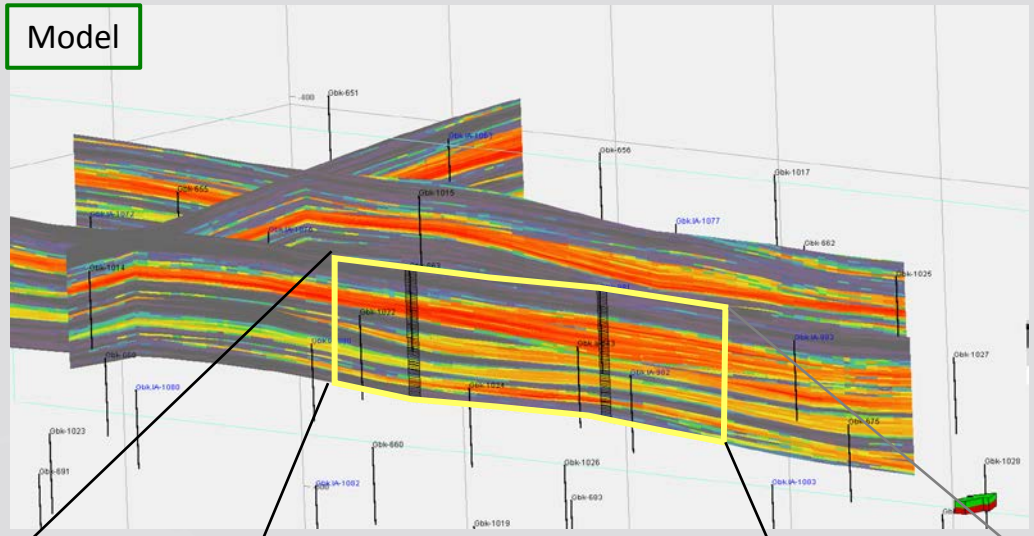


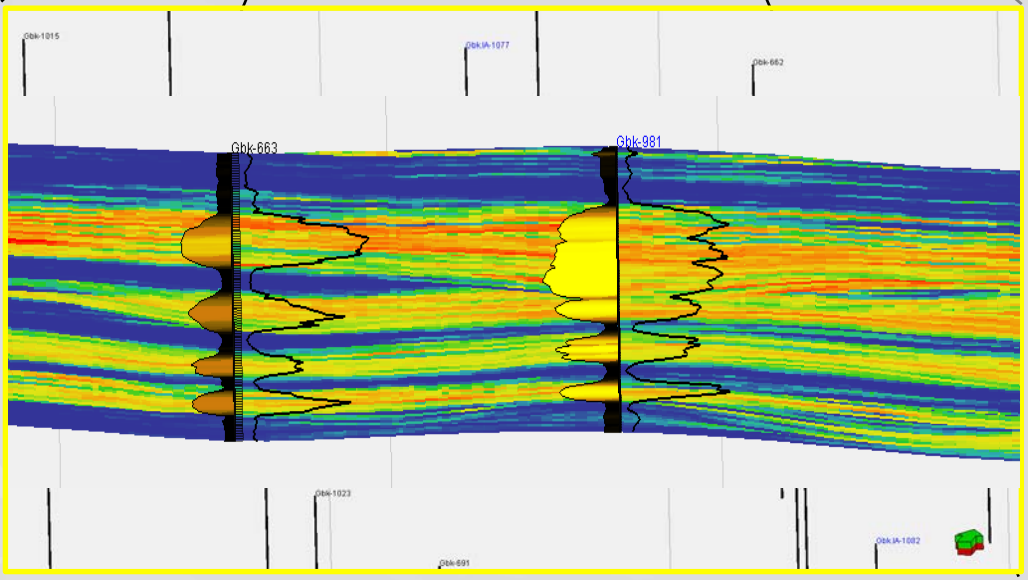
Well



Core

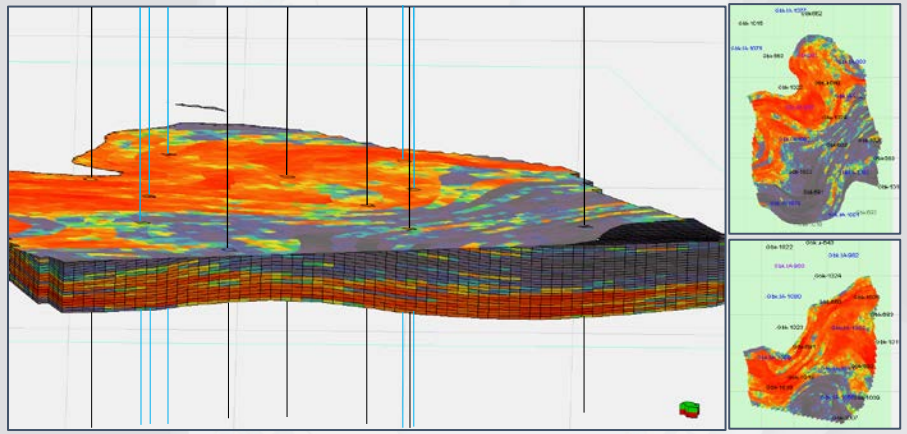
Model





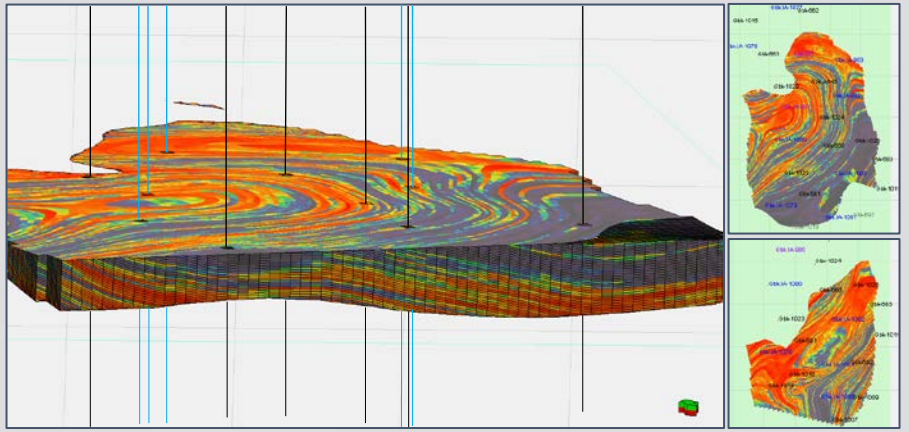
04- RESULTS: CONNECTED VOLUMES

ORIGINAL: Horizontal Layering



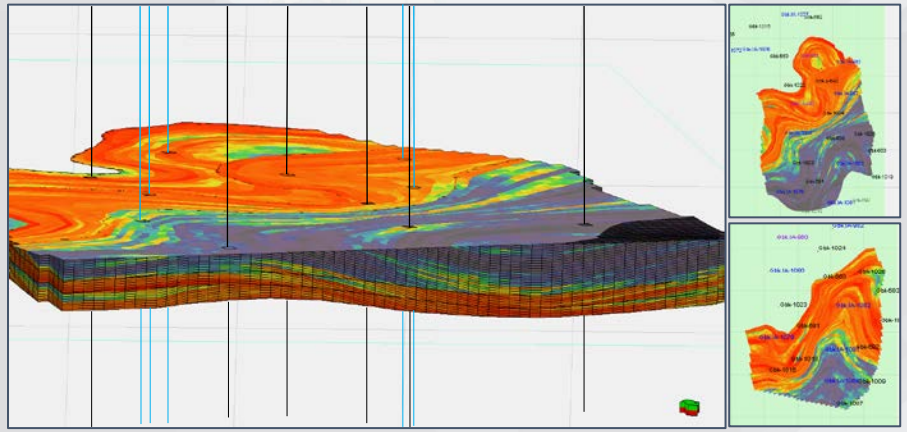
30%

SINGLE CHANNEL: Structured layering



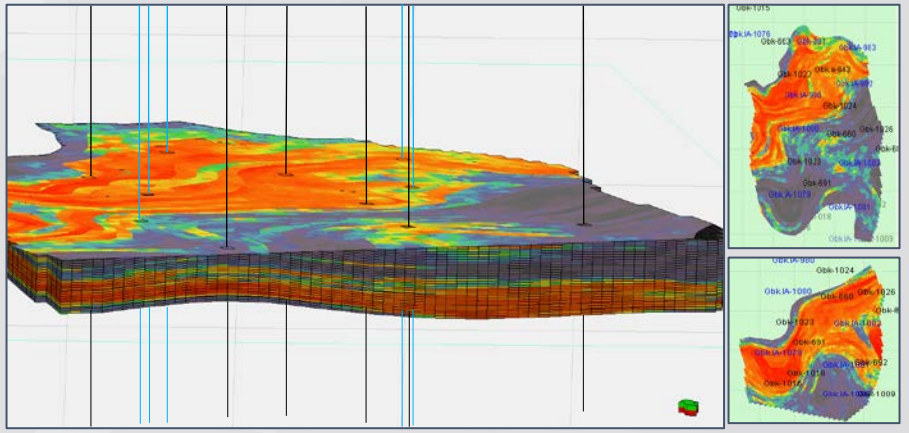
25%

MULTIPLE CHANNEL: Structured layering for multi elements



31%

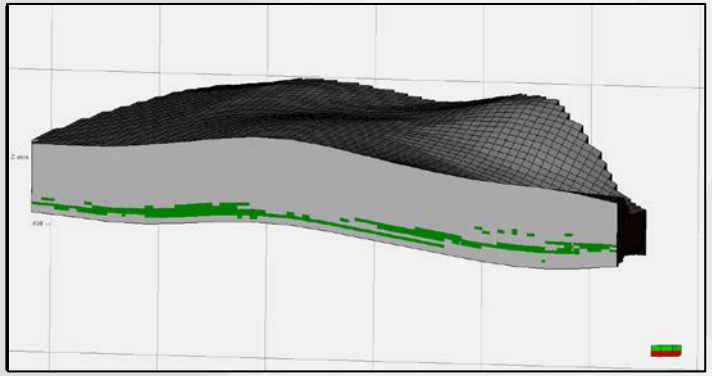
COMPLEX : Horizontal Layering



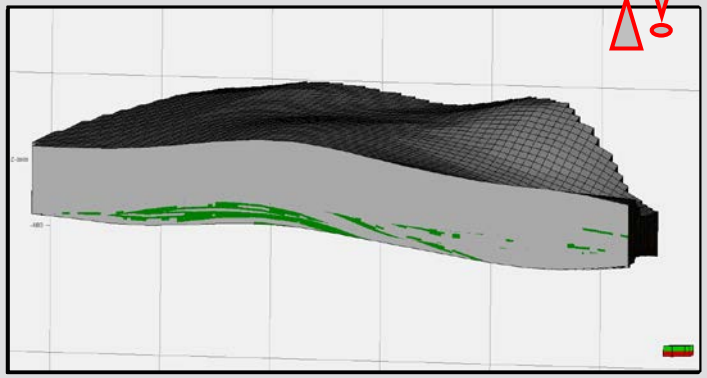
15%

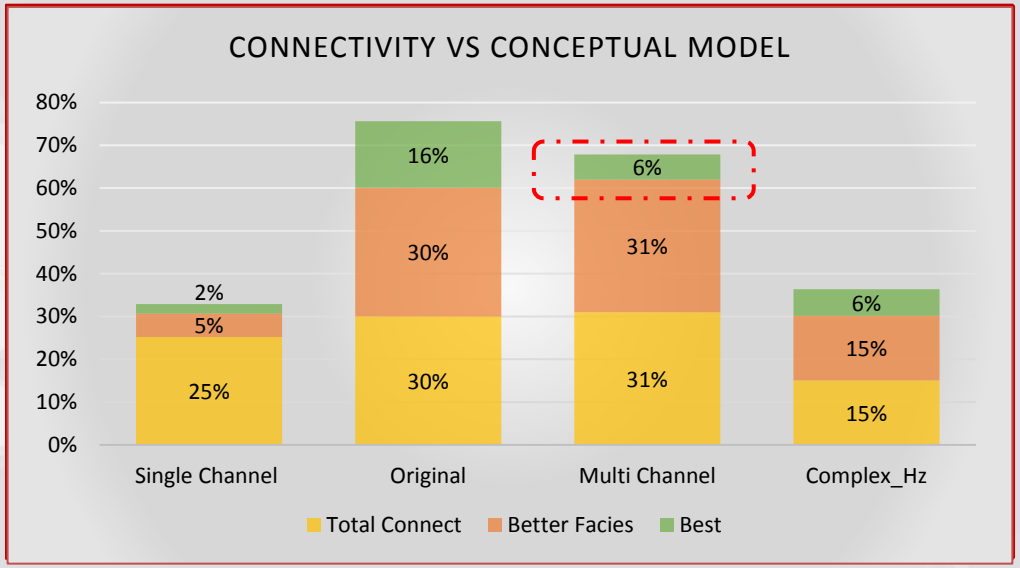
04- RESULTS: CONNECTED VOLUMES

ORIGINAL: Horizontal Layering

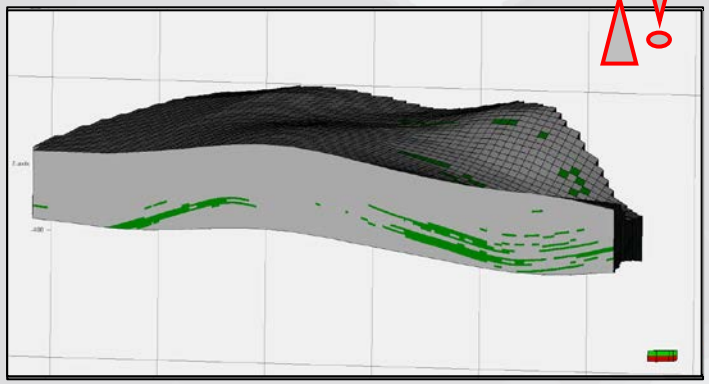


MULTIPLE CHANNEL

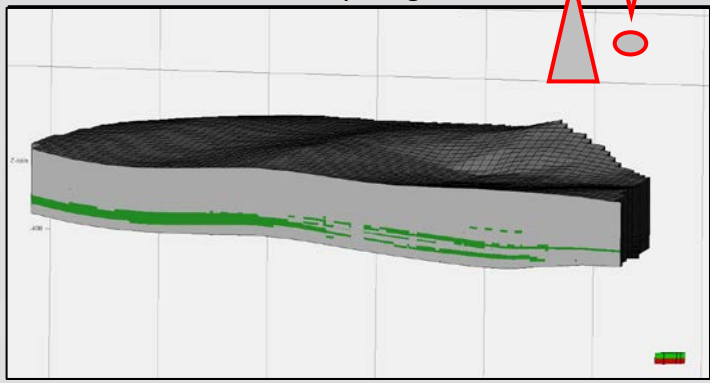




SINGLE CHANNEL: Structured layering



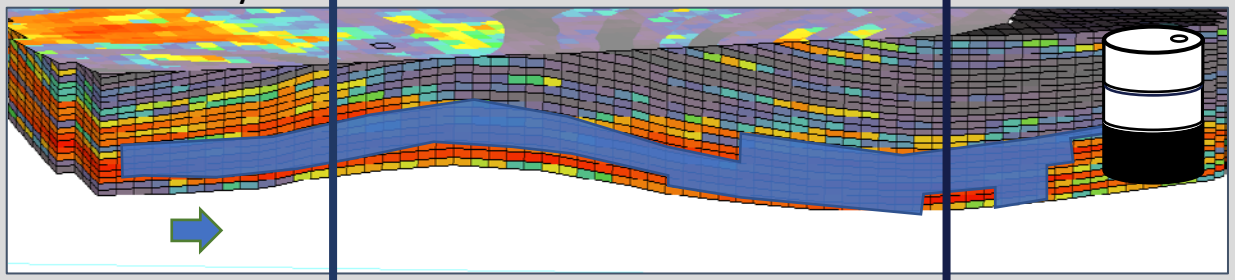
COMPLEX : Horizontal Layering



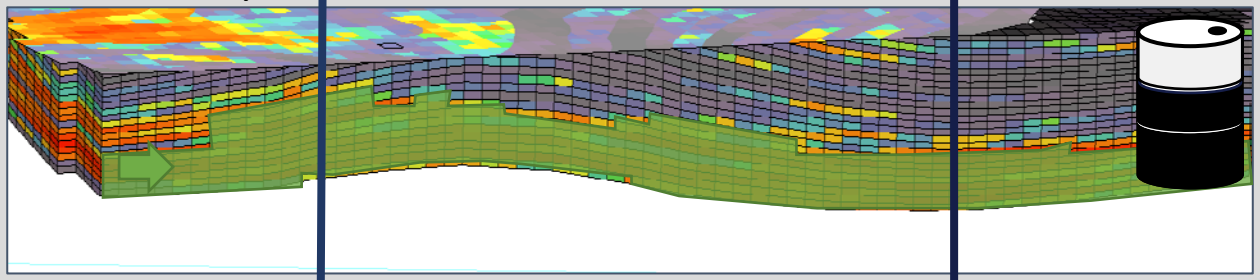
Waterflooding

Polymerflooding

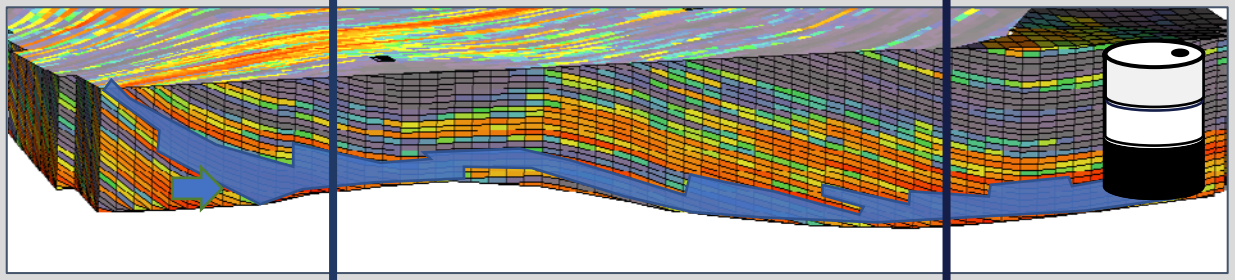
Horizontal Layer



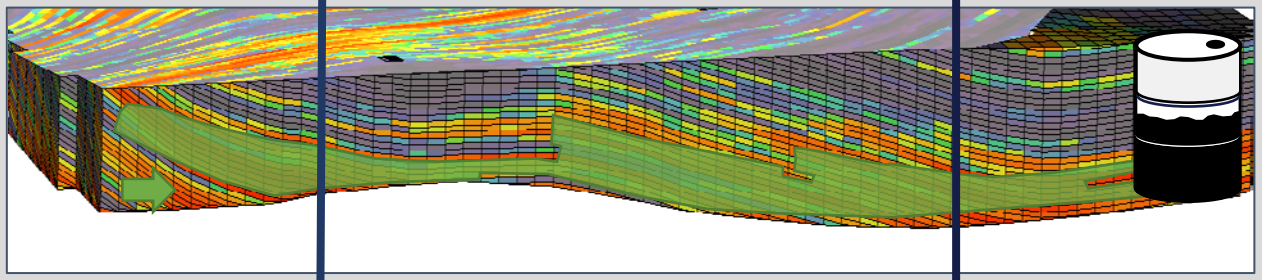
Horizontal Layer



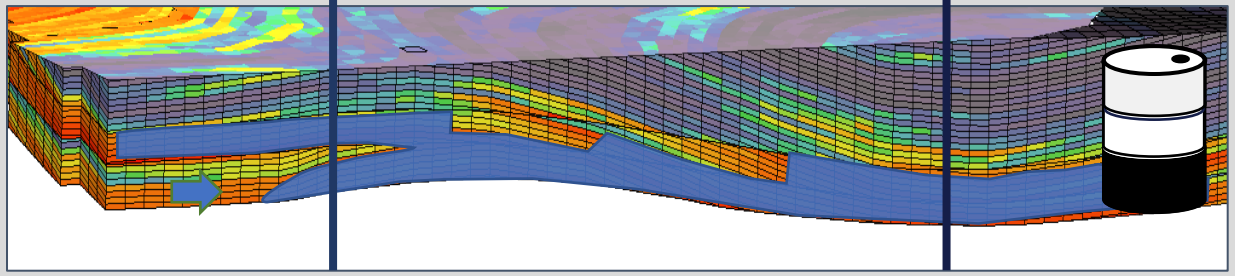
Single Channel



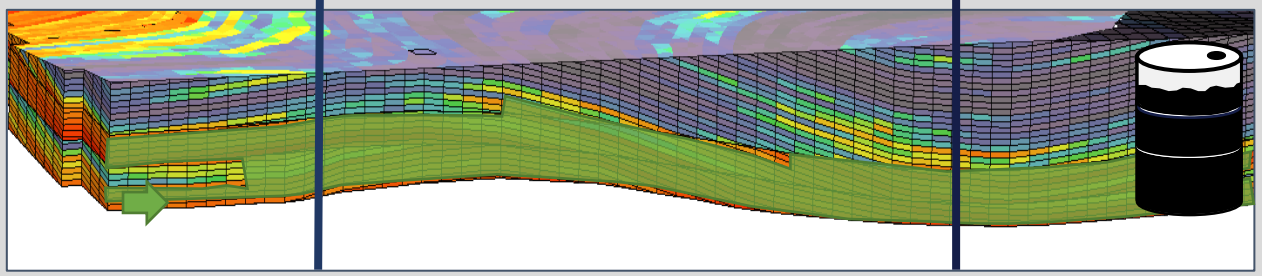
Single Channel



Multiple Channel

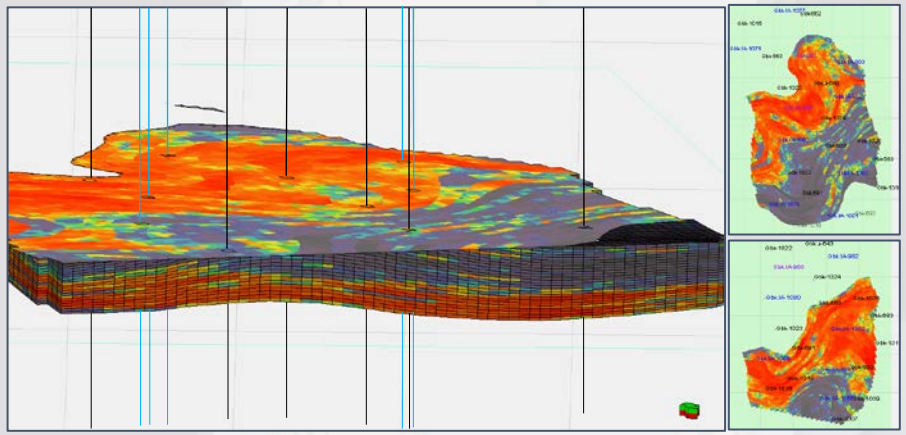


Multiple Channel

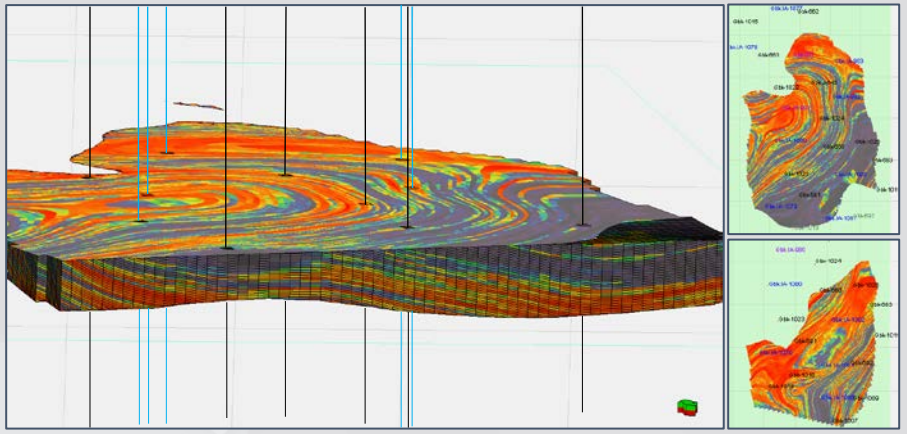


04- RESULTS: EFFICIENCY VARIATION RANGE

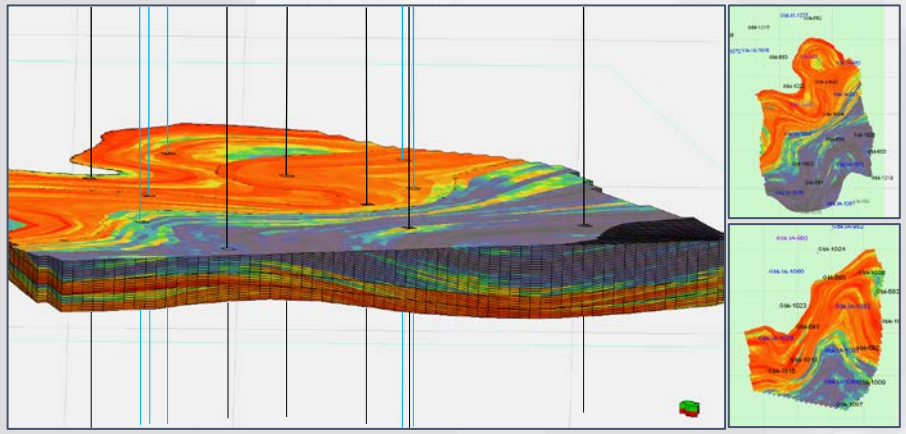
ORIGINAL: Horizontal Layering



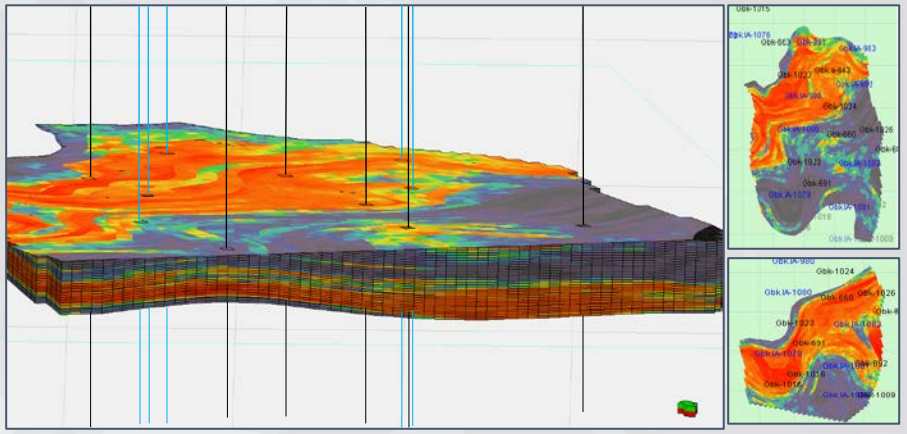
SINGLE CHANNEL: Structured layering



MULTIPLE CHANNEL: Structured layering for multi elements



COMPLEX : Horizontal Layering



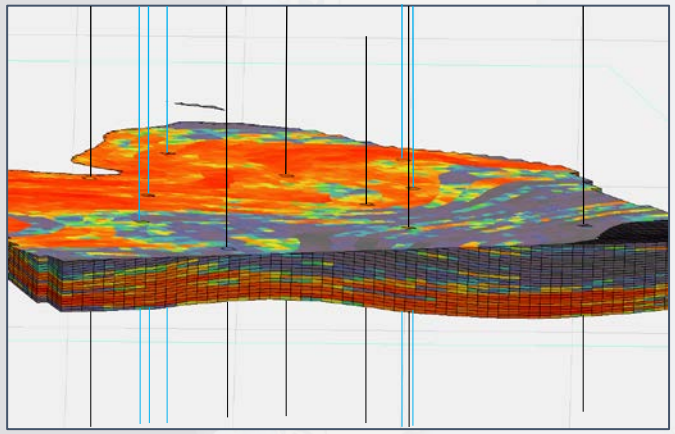
Waterflooding

RF = Ev * Ed

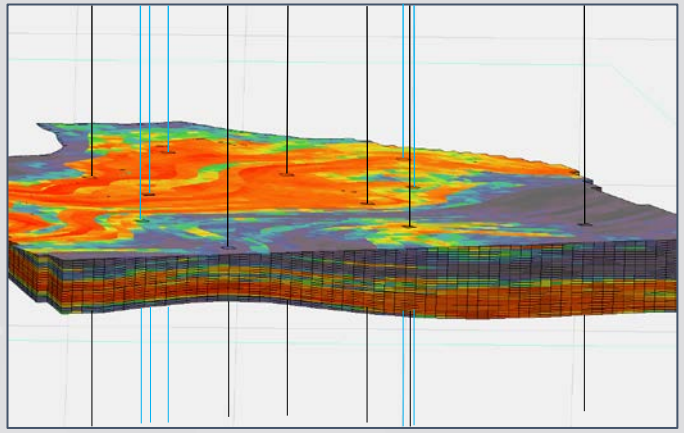
Polymerflooding

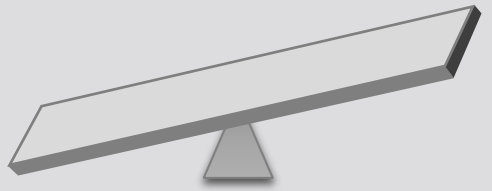
04- RESULTS: EFFICIENCY VARIATION RANGE

ORIGINAL: Horizontal Layering

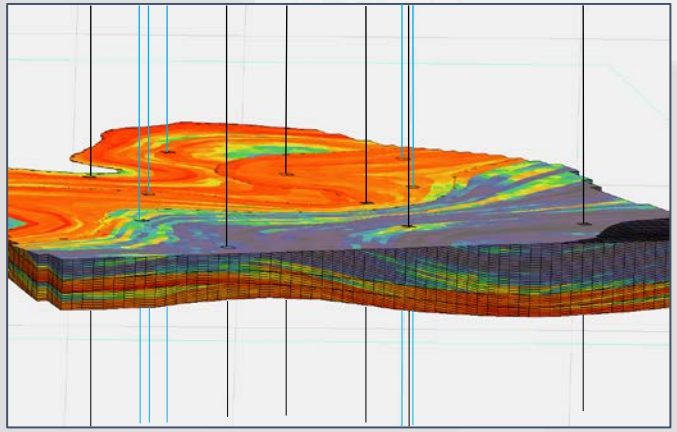


COMPLEX: Horizontal Layering

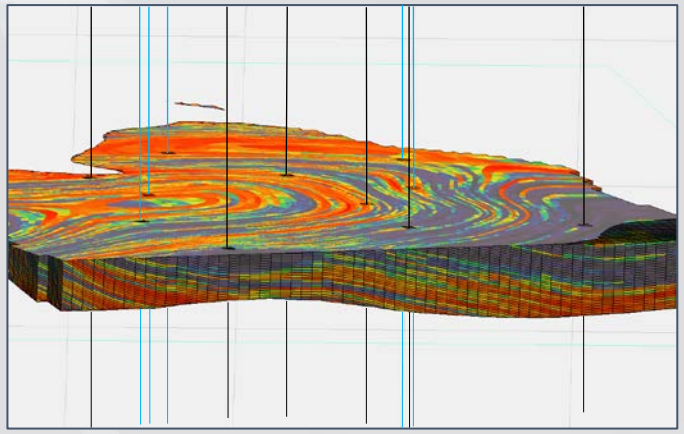




MULTIPLE CHANNEL



SINGLE CHANNEL



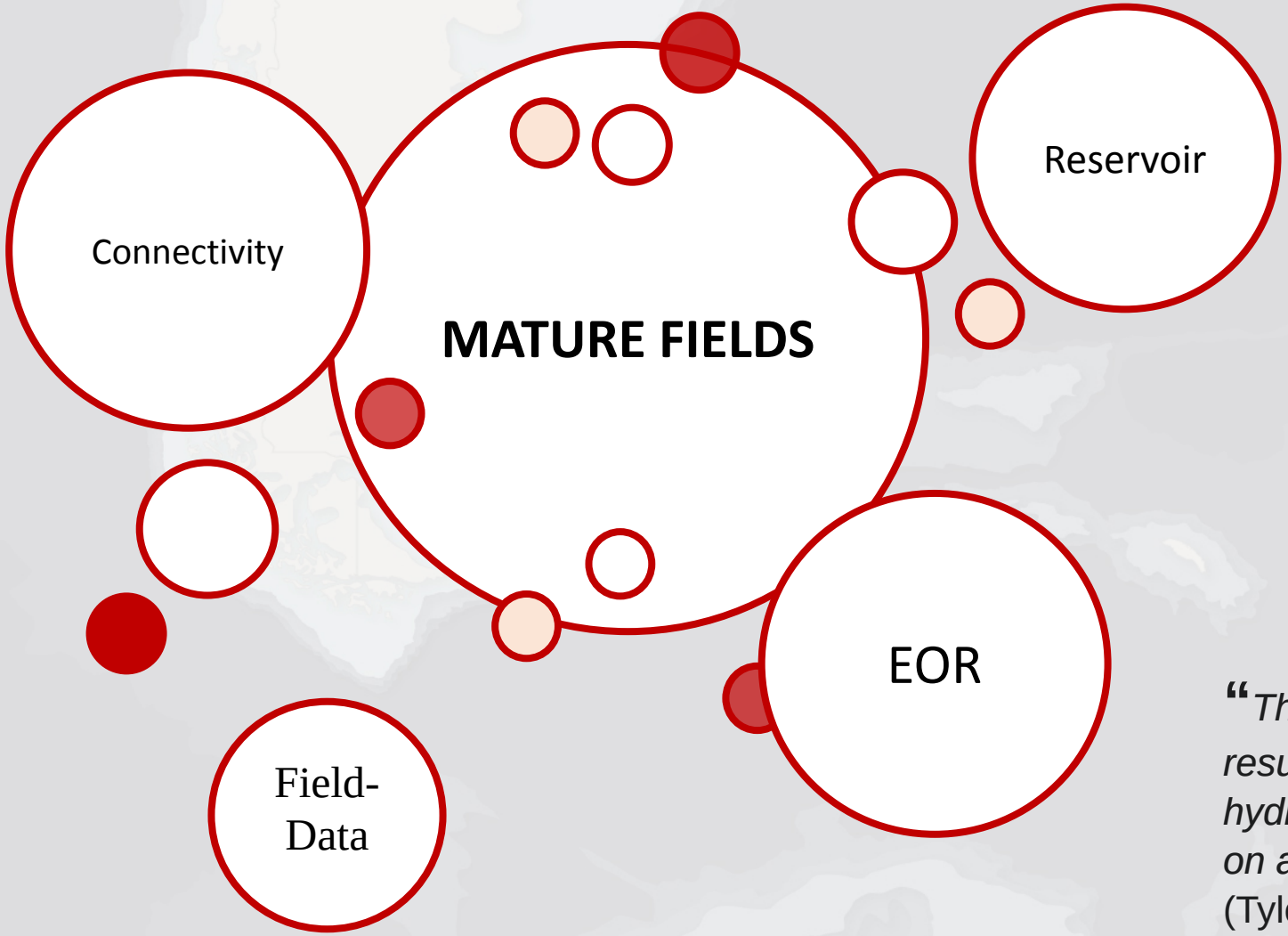
05- CONCLUSIONS: GENERAL CONSIDERATIONS

- ✓ Optimum Incremental Recovery Factor (up to **15%)** can be obtained with an inter-well distance between 20/10 acres for these multilayer fluvial reservoirs

- ✓ The Nature of reservoir complexity will define the area of opportunity
  - *Depositional elements complexity*: Volumetric sweep efficiency can be increased by infill drilling
  - *Internal architecture & facies distribution*: Heterogeneties of the reservoir will lead to more by-passsed oil which becomes a huge opportunity for Polymer (and other EOR techniques) when aiming for Ed improvement

- ✓ The understanding of reservoir heterogeneties and their impact on *Efficiency* becomes critical when aiming to define the most suitable field development strategy

05- CONCLUSIONS: FINAL THOUGHTS



"The heterogeneous nature of meander deposits and resultant compartmentalization makes production of hydrocarbons from these reservoirs difficult, leaving on average more than half of the resources in place" (Tyler & Finley, 1991).