[PS]Construction of Geological Model Scenarios in a Highly Faulted Reservoir: Finding the Appropriate Model That Best-Fit Reservoir Simulation Objectives*

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Abstract

An integrated subsurface modelling workflow (geology, geophysics, petrophysics, reservoir and production engineering) was utilized to rebuild a static and dynamic model of PetroSA's F-A gas field to optimize reservoir management and recovery as well as identify remaining potential for infill well drilling. The last model built was 6 years after production, whereas now in 2018, after 26 years of production, considerably more data is available to guide the model building process.

Subsequent to the first well drilled in 1970 in the F-A field area (F-A1), which encountered hydrocarbon shows in a shallow marine syn-rift sandstone, it was only in 1980 that the true hydrocarbon potential of the so-called F-A gas/condensate field was ascertained. Fifteen follow-up appraisal wells were drilled from 1981 to 1985 to delineate the field, all on the basis of seismic 2D lines. Six of these wells encountered commercially viable gas-bearing reservoirs and provided the basis of the F-A field development with the start of gas and condensate production at the end of 1992.

Over the past 26 years since commencement of production, major technical milestones like seismic 3D surveys in 1986 and 1997/8, history matching studies in 1994 and 1999, a geochemical study in 1998 as well as past and current production and reservoir pressure history have contributed to changes in hydrocarbon estimates and the view regarding reservoir connectivity.

A greatly revised static and dynamic model was built in 2017/18 to replace an old 1999 dynamic model. Static Modelling of the reservoir depends greatly on the accuracy of the structural model, which forms the container into which the reservoir properties can be populated. Structural models were created using different modelling algorithms. The inputs to the structural model were horizon and fault interpretations based on seismic character, fault seal analysis, material balance, and pressure analysis.

Updated petrophysical modelling which includes a facies dependent permeability model and saturation height model was integrated with Seismic attributes like Acoustic Impedance as a secondary variable, to model properties such as porosity away from the wells.

This paper aims to demonstrate the importance of integrating different disciplines to build a robust static model; how different methods of building the structural model impacts on the reservoir simulation; and how the geological understanding has changed since the field was discovered.
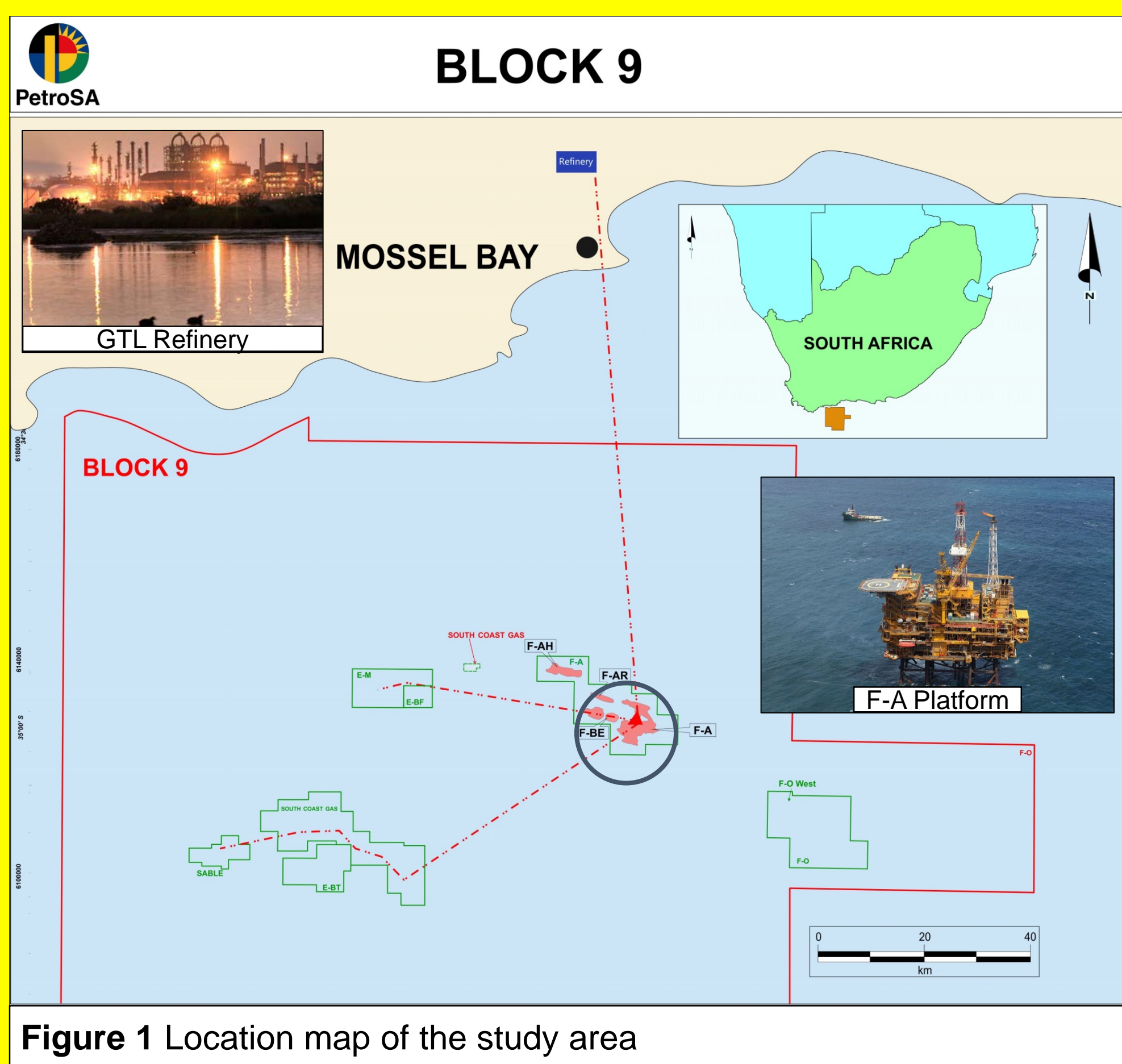
Construction of geological model scenarios in a highly faulted reservoir: finding the appropriate model that best-fit reservoir simulation objectives

PetroSA

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Introduction

BLOCK 9

MOSSEL BAY

GTL Refinery

SOUTH AFRICA

BLOCK 9

F-A Platform

Figure 1 Location map of the study area

Introduction

- F-A Gas Field located 80 km South of Mossel Bay
- Field is first and oldest gas field in South Africa – producing 26 years
- Largest gas field in offshore South Africa
- Supply world's first commercial GTL plant in Mossel Bay

- Highly faulted, geologically complex field
- Several generations of models attempted to capture complexity
- Previous static and dynamic models not adequately updated with recent production data from various fault blocks, leading to miss-match between production, and previous model's GIIP estimations.
- New interpretations changed view and size of field
- Newer computer capabilities, especially computing power and improvements to modeling algorithm are now available, allowing for more detail to be incorporated to models
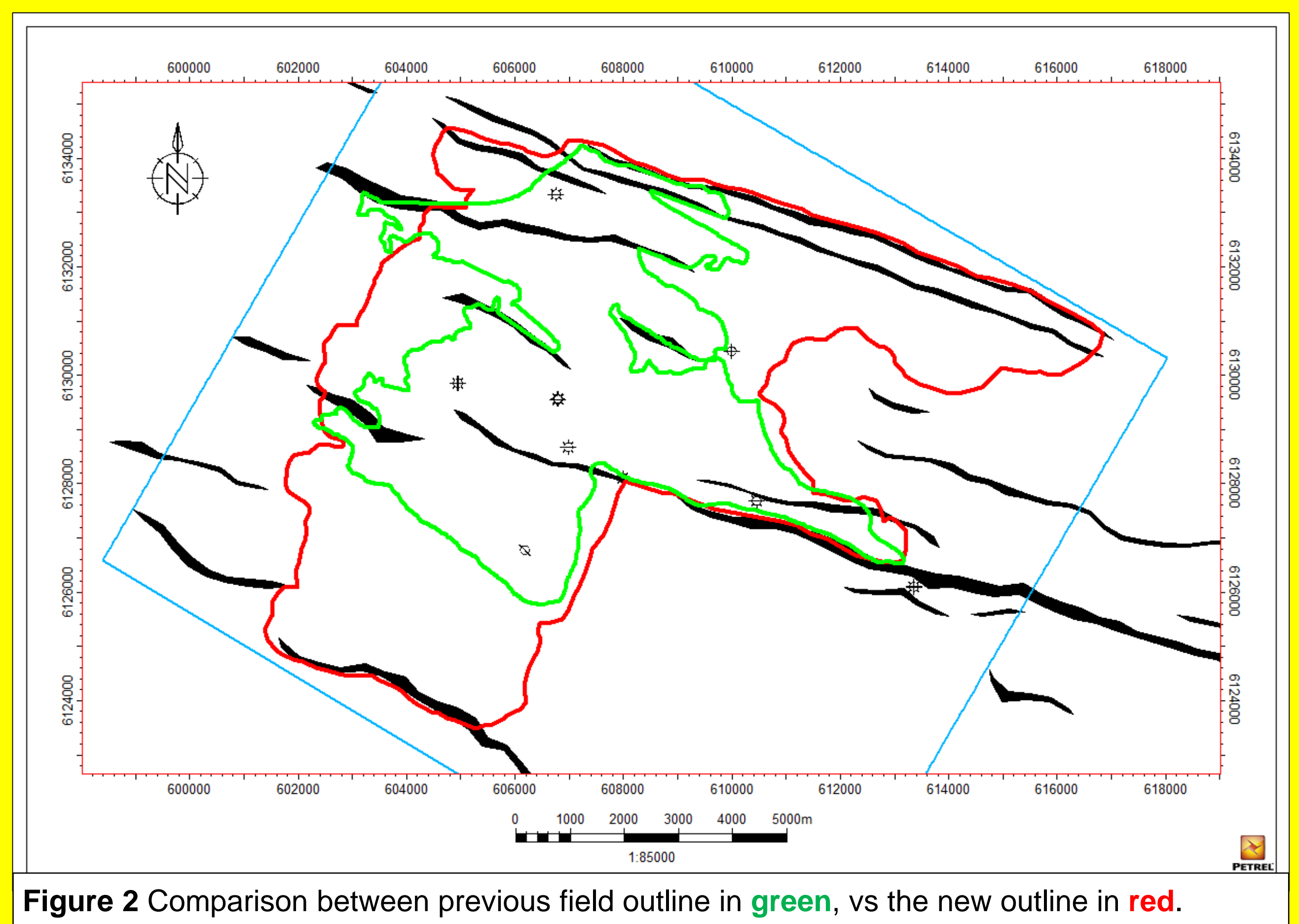
Figure 2 Comparison between previous field outline in **green**, vs the new outline in **red**.

Aims of new study

- Generating an up-to-date dynamic model for good reservoir and field management practice, including preparation for abandonment, using all available geoscience, reservoir and production engineering data.
- Build more detailed static reservoir model, fit for dynamic modeling.
- Quantify the uncertainty in the field to estimate upside potential for the field.
- Assess corner point gridding and volume based modeling to test suitability for dynamic modeling and uncertainty management.
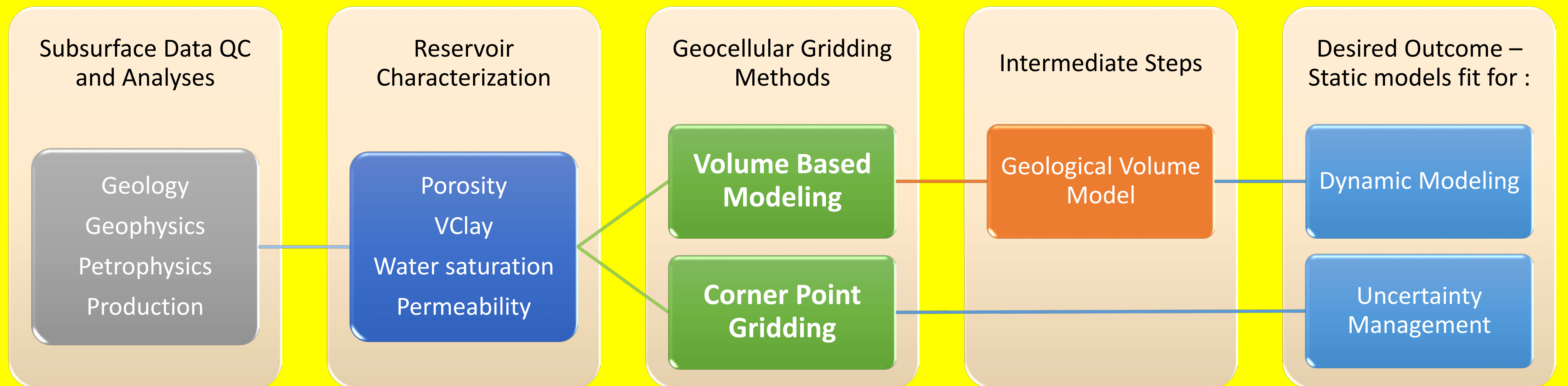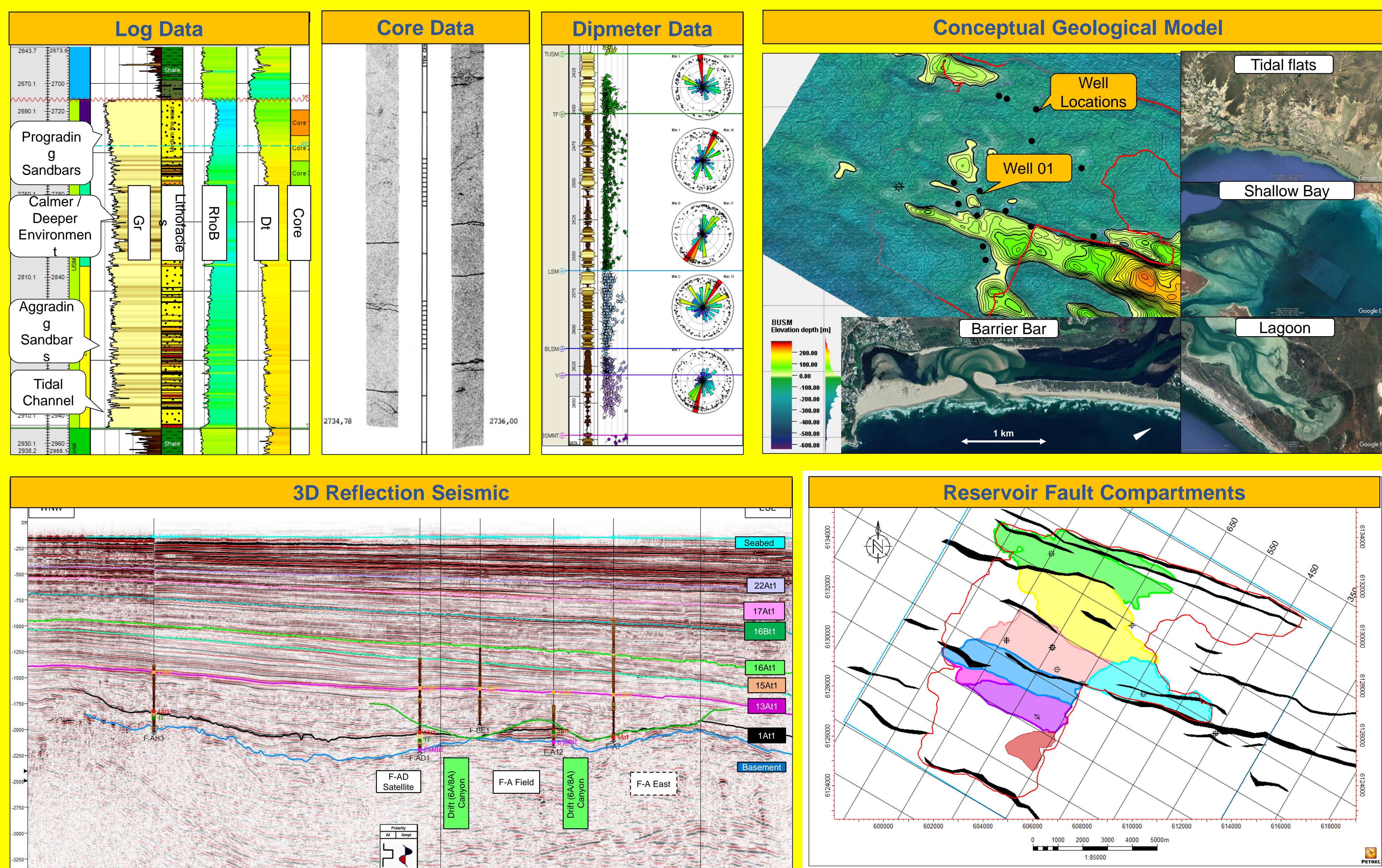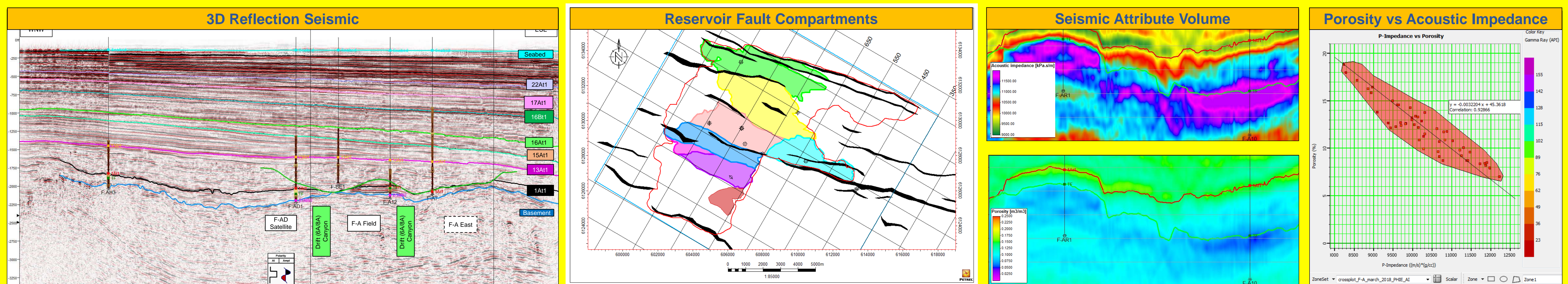
Subsurface Data QC and Analyses:
- Geology
- Geophysics
- Petrophysics
- Production

Reservoir Characterization:
- Porosity
- VClay
- Water saturation
- Permeability

Geocellular Gridding Methods:
- **Volume Based Modeling**
- **Corner Point Gridding**

Intermediate Steps:
- Geological Volume Model

Desired Outcome – Static models fit for:
- Dynamic Modeling
- Uncertainty Management

Figure 3 Workflow adopted to test different modeling approaches best suited for reservoir simulation and resource uncertainty

Subsurface Data QC and Analyses

Log Data

Prograding Sandbars

Calmer / Deeper Environment

Aggrading Sandbars

Tidal Channel

Core Data

Dipmeter Data

Conceptual Geological Model

Well Locations

Well 01

Tidal flats

Shallow Bay

Barrier Bar

Lagoon

1 km

- Core data analyses used to:
  - Identify lithofacies and environments of deposition
  - Determine physical reservoir properties and to calibrate log evaluation
- Dipmeter to aid understanding of depositional and areal distribution trends
- Conceptual geological model using modern analogues to aid understanding of reservoir geometry
- Conventional 3D reflection seismic data interpretation for structural framework (surfaces, faults and compartmentalization)
- Seismic attributes (acoustic impedance) for reservoir property trends (porosity)

3D Reflection Seismic

Seabed
22A11
17A11
16B11
16A11
15A11
13A11
1A11
Basement

F-AD Satellite | Deft (BABA) Canyon | F-A Field | Deft (BABA) Canyon | F-A East

Reservoir Fault Compartments

Seismic Attribute Volume

Porosity vs Acoustic Impedance

P-Impedance vs Porosity

Reservoir Characterization

Gamma | Rhob | DT | Phi | K | Sw

Upscaled Log

Log

Probability Curves

Lithofacies:
- Clean sand
- Fine sandy mud
- Carbonaceous sand
- Shale
- Organic shale
- Calcite cemented sand

Upscaled Phi in sandstone
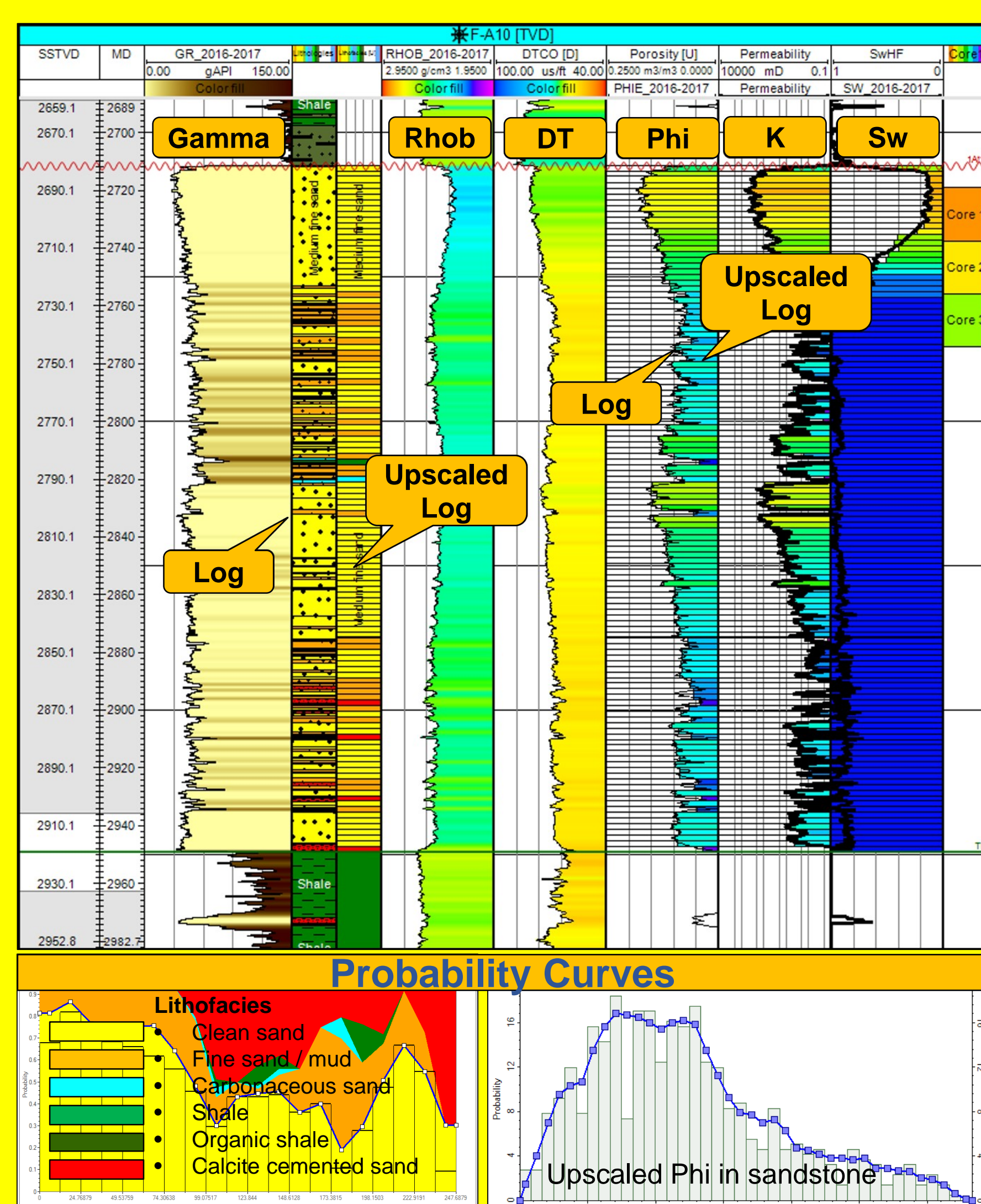
- Petrophysical analyses of well logs to quantify reservoir properties (VClay, Lithofacies, porosity, permeability, net-to-gross, water saturation)
- Water saturation built using height function relating water saturation to height above free water level, based on relationship of capillary pressure to Lambda function
- Upscaling of vertical petrophysical reservoir properties to static model scale
- Statistical analyses of all up-scaled well log data to determine areal distribution probabilities of properties, tied to lithofacies
- Porosity distributed using seismic attribute trends

Dipmeter and derived Variogram

Total sill: 1.0
Nugget: 0.0001
Variogram type: Spherical
Major dir. Minor dir. Vertical
Anisotropy range: 4500   1500   5
Major direction orientation
Azimuth: -70   Dip: 20

Lithofacies
A — B
GWC
Vertical Exaggeration x7

Permeability
A — B
GWC
Vertical Exaggeration x7

Porosity
A — B
GWC
Vertical Exaggeration x7

Net-to-Gross
A — B
Vertical Exaggeration x7

VClay
A — B
GWC
Vertical Exaggeration x7

Water Saturation
A — B
GWC
Vertical Exaggeration x7

Construction of geological model scenarios in a highly faulted reservoir: finding the appropriate model that best-fit reservoir simulation objectives

Geocellular Gridding Methods

Structural Framework

Volume Based Modeling

Intermediate Step

Geological Volume Model

Gridding Step

Orthogonal grid
250m 1:3693

Model Comparisons

A — B

Staircase faults

Corner Point Gridding

Pillar Fault Model

Corner Point Grid
250m 1:3693

A — B

Geologically representative faults

- Models both begin with structural framework consisting of faults and seismic horizons
- Volume based modelling require building of geological volume model as next step
- Corner point gridding needs accurate pillar fault model with as few fault-to-fault truncations as possible
- To build static grid
  - Volume based approach converts volume model to orthogonal grid
  - Corner point gridding results in distorted grid

- Volume based approach results in staircase fault model
- Corner point approach creates geologically representative faults
- Both grids built using 100m x 100m x 2m cell sizing

Outcomes

Dynamic Model Initialization Results

CPG 01 after 8.5 hours
CPG 02 after 6.7 hours
VBM Grid 01 after 5.7 hours
VBM Grid 02 after 5.5 hours
VBM Grid 03 after 1.8 hours

- Several attempts to initialize dynamic models using static models of varying detail, such as different gridding approaches, coarser grids and fewer extra reservoir parameters
- Corner Point grids ran for much longer than Volume Based grids, but halted prematurely
- All Volume Based grids finished running the full time period of 26 years
- Volume Based grids could run much faster

Seismic Depth Conversion Uncertainty

P10 Surface
P10 Surface
P50 Surface
P90 Surface
P100 Surface

Uncertainty Estimation
- Seismic depth-conversion uncertainty affects bulk rock volume estimations
- Monte Carlo Simulation run using averages from Volume Based Model and Structural Gridding approach
  - Purely statistical, no deterministic results
- 125 deterministic static model scenario builds using Corner Point Gridding approach

Uncertainty scenario results

P10 Model
P50 Model
P90 Model

Deterministic Uncertainty Results

Monte Carlo results

Stochastic Uncertainty Results

Conclusions

Corner Point Gridding Approach	Volume Based Modeling Approach
• Generates geologically accurate fault model, has distorted grid pattern	• Perfectly orthogonal static model via structural gridding algorithm, ideal for reservoir simulation
• Dynamic modeling algorithms have difficulty working with distorted grids	• Uses a stair-step model, which is not geologically representative, but easy to work with during dynamic modeling
• Multiple model scenarios could be built rapidly, ideal for uncertainty quantification	• Time consuming to update the volume based model section of the process, making it unfit for uncertainty estimation

Both modeling methods were required to achieve the objectives of this study, namely uncertainty estimation and dynamic modeling

Newer technology necessary to incorporate the best of both modeling approaches

Static and Dynamic modeling software need to develop in an integrated manner

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