Stratigraphic Control on Oil Field Performance in Clastic Reservoirs of the Norwegian Continental Shelf: An Insight from Machine-learning Techniques*

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Abstract

Adequate knowledge of reservoir architecture is key in the placement of injector wells, pressure maintenance, and secondary recovery which in turn can contribute to reserve growth. The main aim of this study is to determine the impact of depositional environment and primary facies architecture on reservoir performance. Fields from the Norwegian Sea, the Norwegian North Sea and the Barents Sea were used to build a database of 91 fields all with more than 11 million barrels of oil in place. A total of 76 clastic reservoirs were classified into three gross depositional environments: continental, paralic/shallow marine and deep marine. 61% of the reservoirs are paralic/shallow marine, 11% are continental and 28% are deep marine. Reservoirs were further classified into eight sub-environments to capture depositional complexity. Representative reservoirs from each sub-environment were analyzed at architectural element scale using logs and core to determine reservoir heterogeneity.

Principal component analysis (PCA) was utilised to identify the importance of stratigraphically dependent variables in the dataset, and to determine the key parameters that have strong effects on the overall variability of the data. PCA reveals that gross depositional environment and sedimentological related parameters dominate the first four principal components. Fluid properties such as API and water saturation are unexpectedly among the less important parameters. A simple box plot of reservoir depositional sub-environment against recovery factor for reservoirs produced via pressure depletion and those supported through water injection reveals weakening recovery with increasing stratigraphic heterogeneity. Delta front, wave-dominated shoreface, tidal non-delta, stacked multistory fluvial and deep marine reservoirs have relatively good recovery, whereas, offshore/transition zone reservoirs and isolated meandering fluvial channel deposits have low recovery.
1.0 What Controls Production?

Hydrocarbon production is controlled by a wide range of factors. The goal of this study is to investigate the relative importance of these empirically by applying modern data analytics to the dataset from the Norwegian continental shelf. Some known controlling parameters are:

- **Geological Complexity**
  - Substantial amount of oil has been bypassed due to a number of reasons
- **Structural complexity**
- **Stratigraphic complexity**
- **Permeability layering**
- **Number of reservoir compartments**
- **Reservoir drive mechanism**
  - Water injection
  - Gas injection
- **Number of wells**
- **Reservoir net: gross**

2.0 Workflow and Methods

**Inputs**
- Reservoir properties
- Structural parameters
- PVT and fluids properties
- Field development properties

**Pre-processing**
- Data partitioning
  - Range/Normalize
  - Data cleaning

**Develop models**
- Initialize model
- Optimize model
- Model validation
- Predict

3.0 What’s in the database?

Parameters recorded for each field include:
- **Geological**
  - Depositional environment (with SAFARI Schema)
  - Structural complexity (Production profile)
  - Diagenetic impact
  - Stratigraphic heterogeneity
  - Mean porosity
  - Average permeability
  - Reservoir depth
  - Reservoir net: gross
  - Total reservoir volume
- **Fluids and Engineering**
  - Hydrocarbon API
  - Drive mechanism
  - Number of producing wells
  - Wells per unit volume
  -GOR
- **Metrics**
  - Recovery factor (estimated for end of field life)
  - Average monthly depletion rate
  - Maximum oil well rate

4.0 Initial Analysis

**Paralic/shallow marine reservoir**
- Gamma, sonic, sedimentological logs, and core images of the Ness and Elise section of the Norma reservoir a subtidal deposit.

**Deep marine reservoir**
- Gamma, sonic sedimentological logs, and core images of the Lista and Neidalt formations of the Grane field showing the distribution of the reservoir intraformational fines.

**Vertical Heterogeneity**
- Measure of the degree of depositional heterogeneity/flow units for the different reservoirs using a scale of 0-6.

**Multivariate Statistical Approach (PCA)**
- Scatter plots
- Eigenvector plot of the first principal component
- Stem diagram showing the relationship between recovery against stratigraphic heterogeneity for all the reservoirs

About SAFARI

SAFARI is an on-going Joint Industry Research Project at UniResearch CIPR and the University of Aberdeen supported by a consortium of currently 14 Oil Companies, the Research Council of Norway and the Norwegian Petroleum Directorate. The goal of the SAFARI project is to develop a fully searchable repository of geological outcrop data from clastic sedimentary systems for reservoir modelling and exploration.

The SAFARI project includes a fully searchable database that is accessed through the website www.safaridb.com The site includes:

- Information from 350 outcrops, including descriptions, logs, photos, sections, reservoir models
- Over 200 of these sections have photo realistic 3D models (Virtual Outcrops) that allow the user to fly around the outcrop in a purpose built web browser
- A tool for identifying modern analogues to reservoirs in GoogleEarth
- Over 6500 geometric measurements of reservoir elements from outcrops
- Vanograms and MPS training images extracted from outcrop analogues

Map of the Norwegian continental shelf showing different wells and field names in the northern North Sea, Norwegian Sea and the Barents Sea. Field names in red have continental reservoir, shallow paralic reservoirs in yellow and deep marine reservoirs in green.
Machine Learning Techniques

5.0 Data Pre-processing

The dataset was normalised using the formula below;

\[ Y = \frac{x - \text{min}(d)}{\text{max}(n) - \text{min}(n)} \times (\text{max}(d) - \text{min}(d)) + \text{min}(n) \]

Where,

- \( \text{Min}(d) \) = Minimum or lowest value in data
- \( \text{Max}(d) \) = Maximum or highest value in data
- \( \text{Min}(n) \) = Minimum value in new range
- \( \text{Max}(n) \) = Maximum value in new range

6.0 Support vector machine Models

A comparison between the three machine learning models trained with a set of 16 most important parameters in the database categorised into geological, engineering and geological/engineering parameters.

7.0 Random Forest Models

A unique database consisting of 32 parameters was developed to evaluate the role of geology in controlling oil field performance.

- The database was used to train and test a set of support vector machine, linear regression and random forest models in order to predict oil fields performance metrics.
- A combination of geological and engineering parameters produced the best predictive models, revealing the importance of some key geology dependent parameters in controlling oil field performance.
- Important geology dependent parameters revealed by these machine learning techniques are: depositional environment, depth of burial, porosity, permeability, initial pressure, stratigraphic heterogeneity, structural complexity and diagenetic impact.

Selected references

