

# High-Resolution Permeability from Borehole Image Logs and Electrofacies Reveals Previously Undetected Features

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## The Challenge

In an unconventional reservoir in northeastern Alberta, Canada, a model for subsurface rock permeability had been created based on the results of Steam Assisted Gravity Drainage (SAGD). When the development wells were drilled based on the reservoir model, the actual results did not conform to expectations, causing the company to lose valuable time and money.

## The Solution

An innovative technique was developed to quantitatively use resistivity borehole image logs in combination with predicted horizontal and vertical permeability curves, to accurately characterize the shaly Inclined Heterolithic Stratas (IHS) within the pay interval. These IHS (~ 2ft thick or less) are below the vertical resolution of the wireline logs; consequently, the integration of borehole image logs improved vertical resolution of the permeability curves down to the cm scale. Through the use of image log analysis and the Geolog<sup>®</sup> Facimage electrofacies analysis and prediction tool, small features were discovered that had been missed in the original analysis, and might have caused the reservoir model to perform against expectations. Had these features been spotted prior to drilling, different production strategies might have been considered.

This case study shows how the integration of core data, conventional wireline logs, temperature logs, borehole images, reservoir saturation logs, and time lapse 4D seismic optimizes production strategy. While the technique was developed and proven to be effective in heavy oil reservoirs, it can be successfully used in any reservoir with shaly IHS.

## Background

The Lower Cretaceous McMurray Formation in Northeastern Alberta contains a substantial portion of the world's proven extra heavy oil resources. It has been estimated that over 40 billion barrels are potentially recoverable using the in-situ Steam Assisted Gravity Drainage (SAGD) process. SAGD involves drilling pairs of parallel horizontal wells, each with a production well and a steam injection well above it, at the bottom of a thick sandstone reservoir.

The ability to predict performance of the SAGD process in the McMurray formation was critical to optimizing development planning and resource management. Since vertical permeability is perhaps the most important geological parameter in predicting growth of the steam chamber during SAGD, capturing the effects of fine geological heterogeneities in reservoir models was crucial to accurately predicting the rate of steam rise and oil/water drainage towards the horizontal producer.

### McMurray formation reservoir properties

Fluvial to Estuarine depositional environment  
Unconsolidated sand: V. Fine to U. Medium grain size  
Porosity: 30 to 35 P.U  
Oil saturation: 80 to 90%  
Permeability: up to 8000 mD  
Oil gravity: 7 to 9 API @12 degC  
Viscosity @ 20 degC: up to 2,000,000 cP  
Pay thickness between 25 to 35 m  
Reservoir depth ~ 500 m

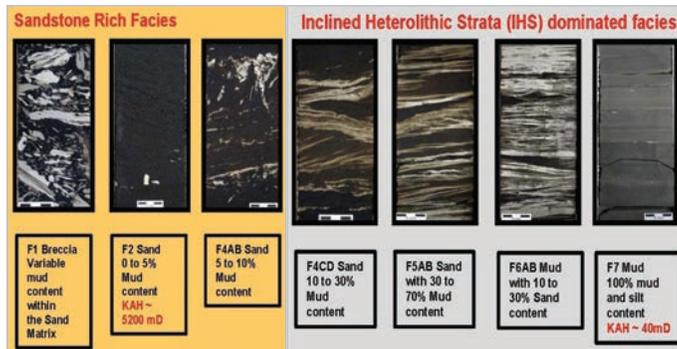
*"By using image log analysis and Geolog Facimage, we were able to characterize small features that had been missed in the original analysis. This enabled us to better understand and improve our predictions of the reservoir production performance."*

» Nader Gerges, Principal Petrophysicist, Statoil, ASA.

### Available data in the study area:

- 193 vertical delineation wells with a full suite of wireline logs and core data (GR, neutron, density, resistivity, high-resolution image log, core porosity, horizontal and vertical core permeabilities).
- 51 vertical observation wells with continuous temperature logs to monitor steam rise.
- 4D seismic time lapse acquisitions to monitor the volume of the steam chamber away from the well.

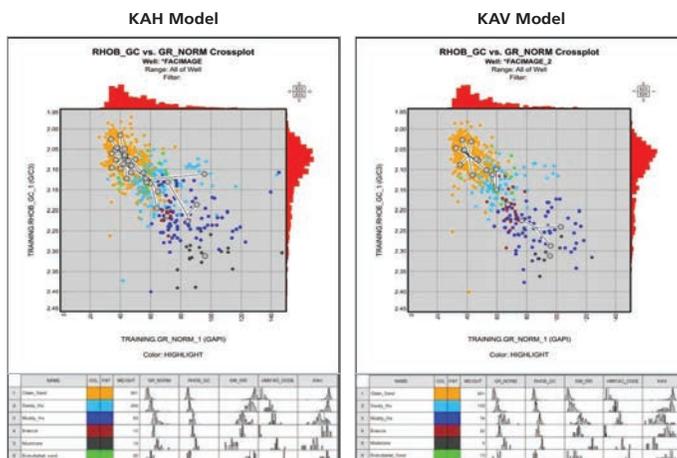
### Facies Classifications:



KAH and KAV permeability models developed using MRGC Facimage module with the integration of wireline logs and core data ONLY:

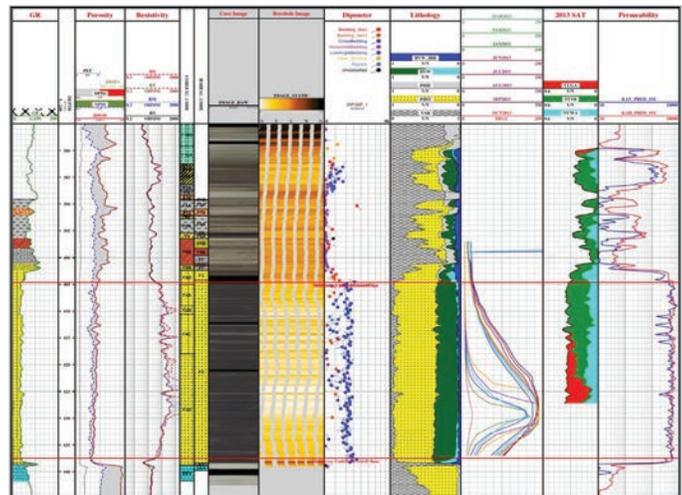
### Input to the permeability model:

- 142 wells with core data
- 857 core plugs for the KAH horizontal perm. model
- 635 core plugs for the KAV vertical perm. model
- 240 wells with borehole image logs
- GR\_NORM curve
- RHOB\_GC curve
- SW\_IRR curve
- K nearest neighbor (KNN=5)
- Facies based permeability model



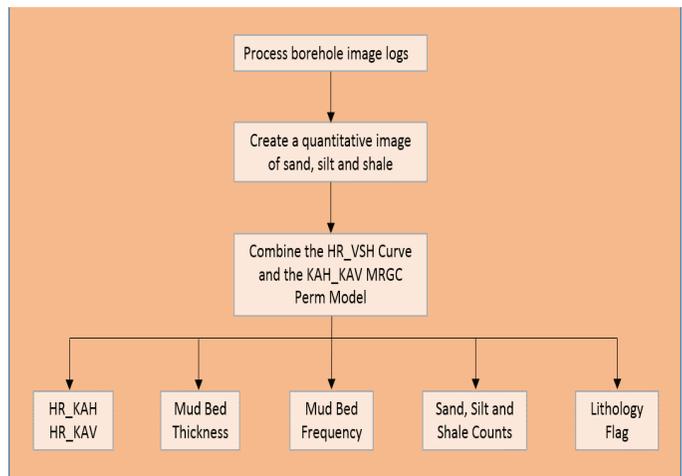
### Permeability model challenges when predicting the top of the steam chamber in an observation well

1. A lack of vertical resolution of the predicted horizontal and vertical permeability curves resulted in overestimating the top of the steam chamber using only the logs.
2. The top of the steam chamber according to the cased hole RST and temperature logs suggested that thin IHS beds of 20 to 30 cm were acting as a barrier to steam rise in the reservoir.
3. As a result, the vertical resolution of the horizontal and vertical permeability curves needed to be enhanced using available borehole images to capture thin IHS beds.

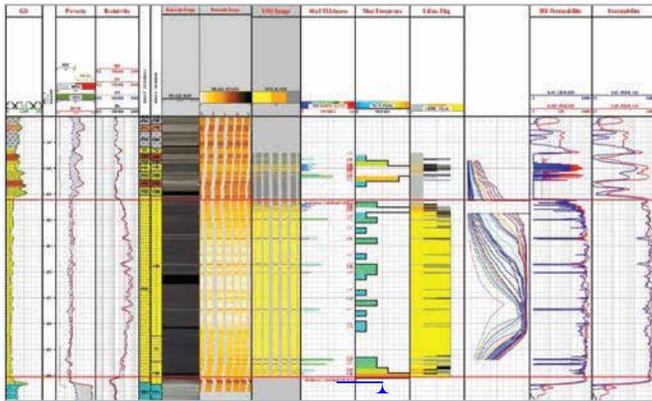


**Conclusion:** Steam chamber growth around observation wells is likely to be controlled by the presence of thin mud beds that can only be detected using high-resolution borehole imaging tools.

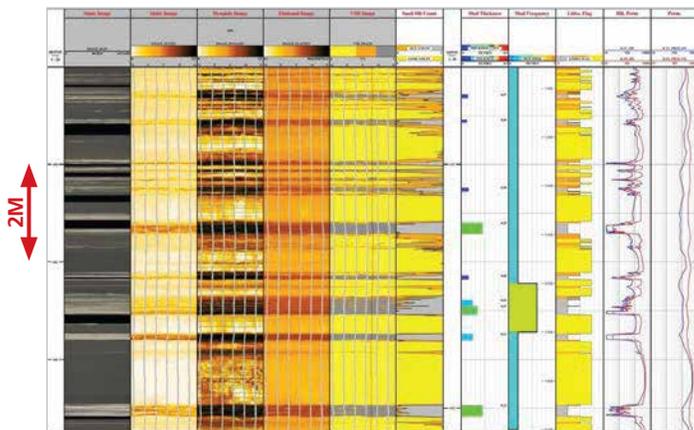
### Workflow to generate a quantitative high-resolution permeability model using the borehole image



**Example of high-resolution permeability curves in the Geolog Image Log Processing and Interpretation tool**

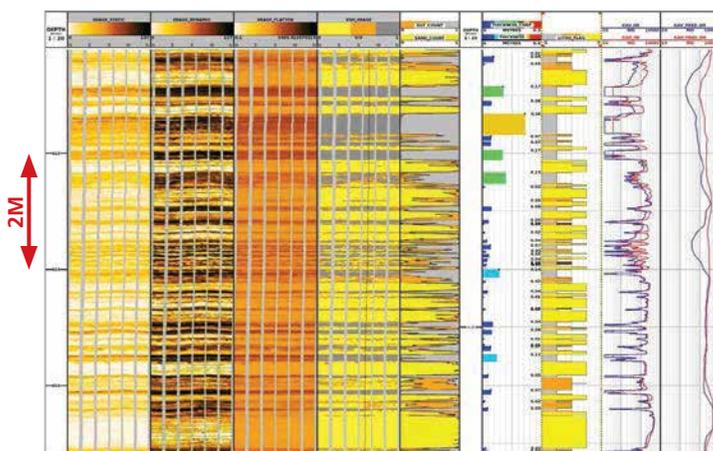


**Example of quantitative borehole image interpretation to generate high resolution permeability curves**



**Conclusion:** The high-resolution horizontal and vertical permeability curve integrated with borehole image logs can capture thin IHS beds down to the 10 cm vertical scale.

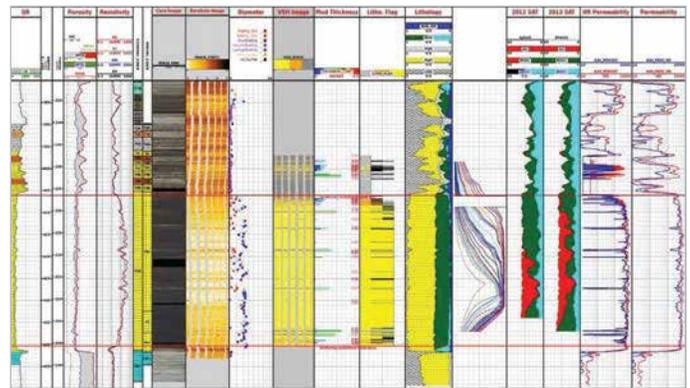
**Example of quantitative image log interpretations to generate high-resolution permeability curves**



**Conclusion:**

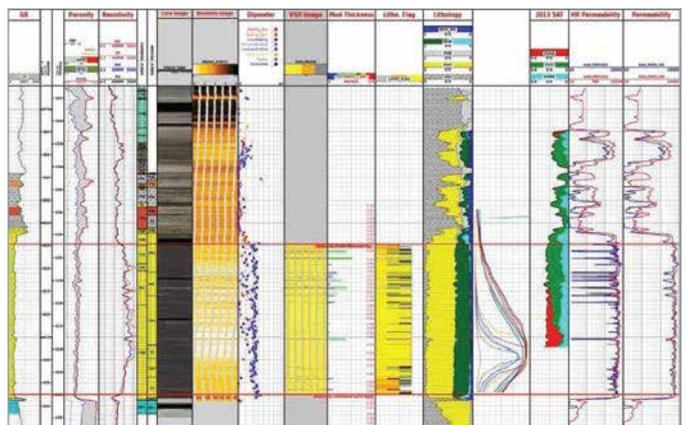
1. Using high-resolution permeability curves in the 3D static reservoir model helps improve reservoir simulation results.
2. An accurate prediction of the location of thin IHS beds within the reservoir improves predictability of the steam rise within the reservoir, thus improving reservoir production performance.

**Example of a temporary baffle:** In an observation well 5m away from the steam injector, thin beds of 5 to 15cm are creating steam traps that affect oil drainage vertically towards the producer.



**Conclusion:** It's very clear that the thin beds captured by the high-resolution permeability model are in line with the top of the steam chamber seen from the cased hole saturation log. When the original permeability model was used in the 3D reservoir model, it incorrectly predicted that the steam would reach the top of the reservoir much faster than it actually did.

**Example of a possible barrier due to the frequency of thin mud beds.**



The effects of thin beds can be dramatic on the vertical growth of the steam chamber, resulting in a loss of oil production from the upper half of the oil column. Using the new technique, it was possible to identify these barriers ahead of time, helping to improve the predictions.

