Sedimentary particle size distribution in seismic domain: A high resolution data interpretation for geo-mechanical applications

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Summary

A deterministic workflow for multi-scale data integration and interpretation is introduced. The key reservoir properties of sub-seismic scale, such as porosity and permeability distribution honoring the non-linear relationships have been successfully interpreted from the kilometer-scale inverted post-stack seismic data. Grain size distributions from the core data, borehole wireline logging data and the post-stack seismic data have been utilized in building the links between the rock elastic properties and the seismic properties. The complex reservoir heterogeneity and the internal reservoir architectural elements of the bitumen bearing McMurray Formation were interpreted with great detail in centimeter-scale using a novel method of high definition facies templates. The new approach to facies-template-based rock elastic property values has proved to be the key for major geo-mechanical applications, such as fluid substitutions, reservoir rock integrity verification or cap rock integrity evaluation.

Introduction

Bitumen bearing reservoirs are very complex and different from the conventional oil reservoirs. The density of the bitumen is almost the same as the water density (API of 10). Highly viscous bituminous reservoir often contains a zone of high water saturation, referred to as lean zone and can act as a thief zone by drawing heat away from the bitumen. Occurrence of seismic and sub-seismic scale impermeable shale-plugs can increase the reservoir complexity to even worse. A very detailed subsurface study of the reservoir heterogeneities is essential for in-situ technology, such as Steam-Assisted Gravity Drainage (SAGD). This has an impact on both the resource assessment and the recovery efficiency. Conventional seismic interpretation has its limitations in the resolution (less than a meter level) to properly describe small-scale heterogeneous architectural elements, which have distinct reservoir properties and a huge influence on the geo-mechanical behaviors.

Rock physical properties, such as rock's bulk modulus, shear modulus and density are directly related to the seismic properties and subsurface geological facies. The challenge is the data integration with multi-scale resolution, especially when the desired outcome is geo-cellular modeling for geo-mechanical applications. All the ambiguity is related to reservoir heterogeneity which is an aspect of complex geology. In order to account for the many uncertainties in the geology, an aggregate approach of lithofacies and high definition facies templates (Alam et al., 2017) has been implemented for various rock properties. Many of the targets in heavy oil fields have been explored extensively in the past with varying degrees of success. The vertical and spatial extents of the geological trends have been well established in the literatures. The geology of the studied area is already described by many authors, such as Mossop and Flach (1983), Smith (1988) and Fustic et al. (2013). The current study focused on geological facies in the form of facies assemblages (Alam et al., 2015), such as depositional architectural elements that have similar reservoir properties in the seismic volume and are stochastically derived from the well locations using the novel high definition facies templates, such as the 3D permeability distribution.

Theory and/or Method

Interpretation of the sub-seismic scale facies were essentially needed to rely on well log data and core data with underlying prediction of the depositional processes that controlled the facies distribution. Well data and core data provided high resolution (centimeter level) vertical distribution and seismic data became the most vital source of information in obtaining the spatial distribution in terms of the facies in between the wells. Rock physical properties and the related seismic attributes were represented by the related facies and hence made the relationships with the observed properties in the wells and their lateral distributions. Rock's geo-mechanical properties, such as rock's bulk modulus and shear modulus were successful in establishing the facies-by-facies links between reservoir properties and their elastic responses.

Rock's geo-mechanical properties, such as incompressibility (lambda), rigidity (mu) and density (rho) are linked to the fine particle volume (FPV) ranges of different facies templates. High definition facies templates were used in building the high resolution (centimeter level) near-wellbore images. Facies distribution and reservoir properties between the wells were extracted and mapped from the FPV data volume built from the inverted post-stack seismic volume. Each facies template is constructed based on the observed FPV in the core samples and incorporated with the sedimentary structures on the samples. This method honoured the heterogeneity of each facies for the realistic porosity-permeability distribution. The directional permeabilities were distributed through out the facies utilising the flow-simulation based tensor method and preserving the data integrity for upscaling. This is unlike conventional porosity-permeability linear correlation based approach. These values have been verified with the laboratory measurements for the data integrity.

Examples

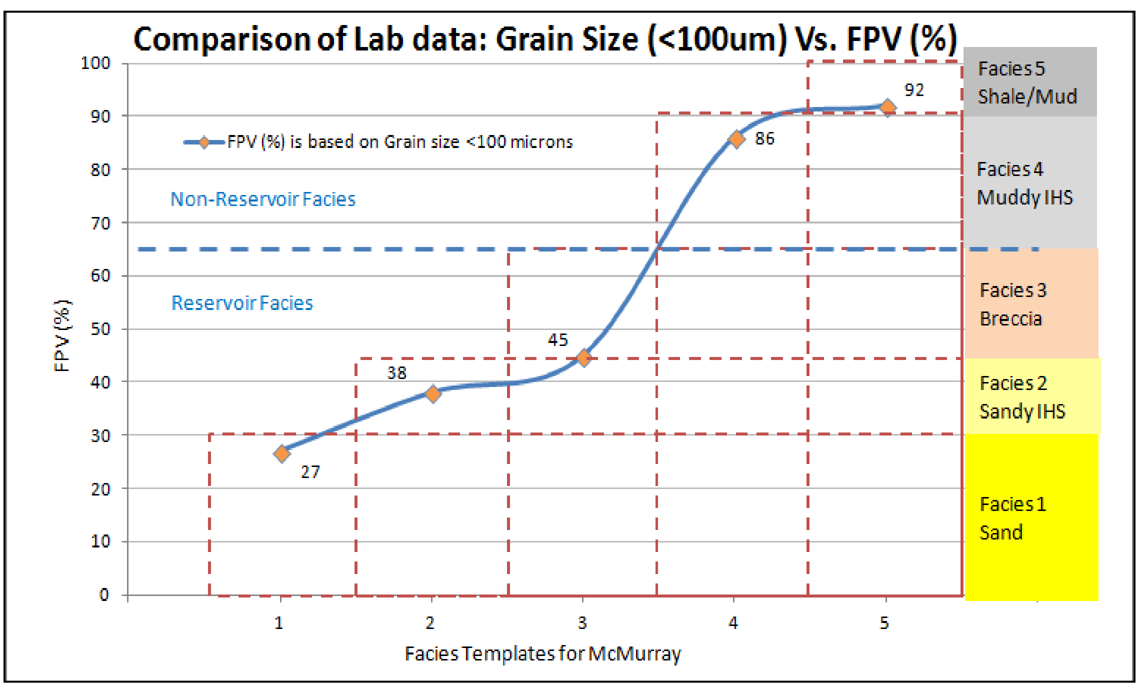

Figure 1: Relationship of the grain sizes of the FPV and the high definition facies templates.

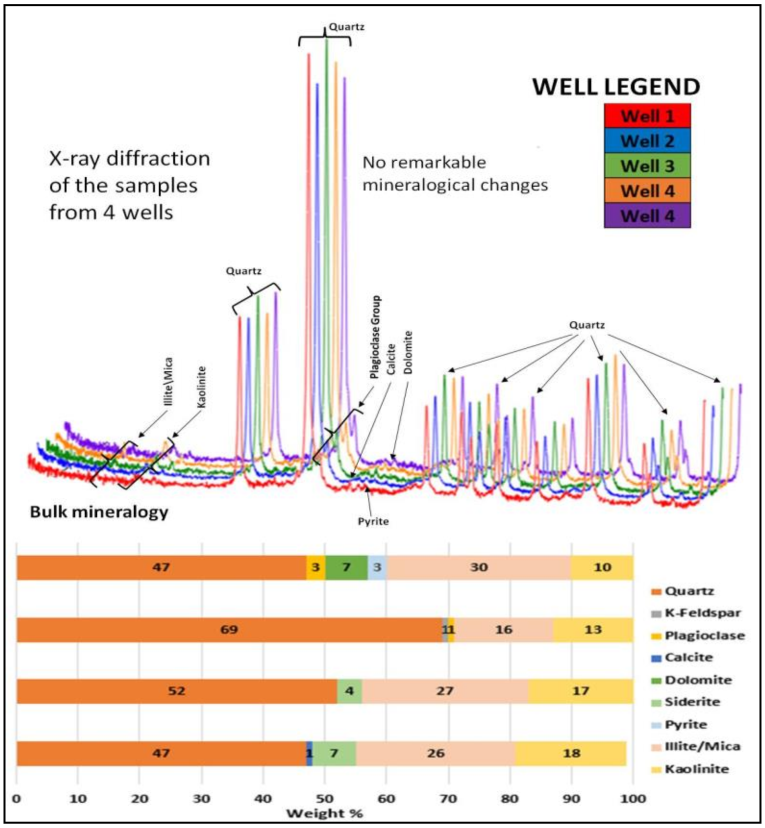

Figure 2: XRDs show the clay mineralogy of all the four wells.

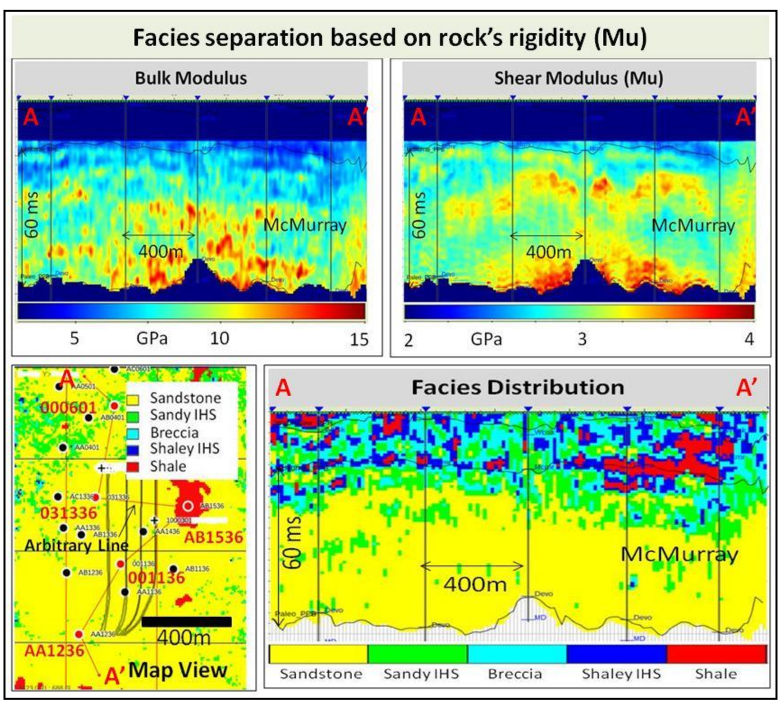

Figure 3: Rock's elastic properties derived from seismic were used in separating facies distributions from the inverted seismic volume.

Conclusions

This study focused on the heavy oil bearing Cretaceous McMurray Formation in northern Alberta. The internal reservoir architecture, such as stacked channel bars, inclined heterolithic strata (IHS), and shale plugs are intricate due to reservoir heterogeneity. Drilling success or optimum oil recovery will depend on whether the reservoir model accurately describes this heterogeneity. Thus, it is very important to properly identify the distribution of the permeability barriers and shale-plugs in the reservoir zone along with cap rock integrity for the steam injections.

A new approach to facies-template-based rock elastic property values have been utilized in this study with the goal of accurately predicting and mapping rock properties from an inverted seismic volume. Geological facies verification in terms of rock physical properties and seismic attributes using high definition facies templates was found to be very useful in seismic data interpretation. The rock's physical parameters, such as bulk and shear moduli, are its compressibility and rigidity, which are aligned with facies variations as shown in this study. Fluid substitution verification, based on the different facies classes, was found to be compatible with FPV values. Dense vertical well control and dozens of horizontal well pairs over the area of investigation confirm a very good correlation of the geological facies interpreted between the wells from the seismic volume and validate the high resolution (centimeter leve) seismic data interpretation. This method allows the geological, geophysical, petrophysical and rock physical information to provide facies information to a geo-cellular model that enables quantitative analysis of reservoir properties for geo-mechanical evaluation and applications.

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References

1. Alam, M., L. Ibna-Hamid, J. Embleton and L. Lines, 2015, Synthetic core from conventional logs: A new method of interpretation for identification of key reservoir properties, Interpretation, Vol-3.1 (2015), pp. SA1-SA14.

2. Alam, M., S. Makoon-Singh, J. Embleton, D. Gray and L. R. Lines, 2017 (in-press), Interpretation of geological facies in seismic volume using key rock elastic properties and high definition facies templates, Interpretation, Vol.5, No.2 (May, 2017); p. 1-17.

3. Fustic, M., D. Cadiou, D. Thurston, A. Al-Dliwe, and D. A. Leckie, 2013, Reservoir modeling by constraining stochastic simulation to deterministically interpreted three-dimensional geobodies: Case study from Lower Cretaceous McMurray Formation, Long Lake steam-assisted gravity drainage project, Northeast Alberta, Canada, in F. J. Hein, D. Leckie, S. Larter, and J. R. Suter, eds., Heavy-oil and oil-sand petroleum systems in Alberta and beyond: AAPG Studies in Geology **64**, 565 – 604.

4. Mossop, G.D., and P. D. Flach, 1983, Deep channel sedimentation in the Lower Cretaceous McMurray Formation, Athabasca oil sands, Alberta: Sedimentology, v. 30, p. 493-509.

5. Smith, D. G., 1988, Modern point bar deposits analogous to the Athabasca oil sands, Alberta, Canada: *in* Tide Influenced Sedimentary Environments and Facies, P.L. de Boer, A. Van Gelder and S.D. Nio, eds.: Dordrecht, D. Reidel, 417-432.