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Reviving a SAGD Legend: A Robust 3D Geological Model for AOSTRA's UTF Phase A to Support Reservoir Geomechanical Simulations History Matched to Reservoir and Tunnel Responses

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Abstract

AOSTRA Underground Test Facility Phase A is the first pilot test for SAGD process. It consists of three well pairs with a 60 m horizontal completion section in the oil sands reservoir. The project included a tunnel developed in limestone ~15 m below the reservoir. The tunnel served as a starting drilling point for the three well pairs and instrumentation stations to monitor the responses of the underburden formation. The project had an extensive monitoring program to study various responses such as temperature, pressure, and horizontal and vertical movements. This comprehensive monitoring program created a unique opportunity to evaluate different responses to the SAGD process, such as steam chamber propagation and dilation. Accurately analyzing these responses requires a detailed 3D coupled reservoir geomechanical simulation. The backbone of such simulations is a robust geological model that can capture the necessary heterogeneity. To the authors' knowledge, a 3D geological model of this project does not exist as all previous simulations were performed in 2D. This study presents the development of a 3D geological model and compares it with core data and previous 2D geological interpretations. Discrete facies logs were modelled using Sequential Indicator Simulation (SIS), while continuous petrophysical properties such as porosity and permeability were distributed using Gaussian Random Function Simulation (GRFS). The average values of porosity, permeability, and oil saturation for the oil sands reservoir are 0.26, 1.5 D, and 0.82, respectively. The facies model plays a crucial role in developing robust petrophysical distributions, which highlights the importance of an accurate facies model. The final comparison against both core data and previous 2D interpretation shows a high compatibility, which boosts the reliability of the 3D developed model. The final model defines the foundation for future reservoir geomechanical simulations of UTF Phase A that will be history matched against temperature, pressure, and deformation measurements in the reservoir and the underlying tunnels.

Introduction

Established in early 1983 by the Alberta Oil Sands Technology and Research Authority (AOSTRA), the Underground Test Facility (UTF) represented a pioneering initiative aimed at evaluating Dr. Roger Butler's Steam-Assisted Gravity Drainage (SAGD) concept alongside underground mining access methods for bitumen extraction. Situated 65 km north of Fort McMurray, the facility was officially inaugurated in 1987, featuring two 200-meter-deep shafts that provided access to tunnels within Devonian limestone directly beneath the oil sands. This configuration enabled engineers to drill injection and production wells upward into the reservoir. Following the success of the initial Phase A pilot, which commenced steaming in December 1987 utilizing three short horizontal well pairs, the project secured industry funding for an extensive Phase B expansion, involving 500-meter completion lengths. The UTF tests ultimately achieved a 65% bitumen recovery rate, surpassing the initially predicted range of 30%–45%, and established in situ recovery as a standard production technique that revolutionized the Canadian petroleum industry.

For Phase A SAGD trials, AOSTRA and CANMET jointly sponsored a comprehensive geotechnical program to monitor safety and assess geotechnical impacts on steaming processes. The program comprised four components: surface instrumentation, tunnel instrumentation, laboratory testing, and numerical modeling. The surface instrumentation, which included thermocouples, piezometers, extensometers, and inclinometers, provided valuable data on reservoir response during Phase A. Tunnel instrumentation monitored underground opening integrity through thermistors, extensometers, and convergence points, showing minimal rock displacements and no unsafe conditions. Laboratory testing encompassed mechanical and thermal tests on oil sands, shale seams, and limestone formations, including triaxial compression tests and specialized stress path testing on oil sands. The numerical modeling program aimed to understand SAGD reservoir geomechanics through two approaches: analyzing an 2D ideal cross-section to identify behavioral mechanisms, and modeling actual Phase A geology while comparing predicted and measured displacements.

UTF Phase A Geology

The UTF, located 65 km northwest of Fort McMurray, is situated within the Athabasca oilsands region, which extends over an area of approximately 93,000 km2 (Hein & Cotterill, 2006). The

stratigraphy of the Athabasca region consists of Lower Cretaceous Grand Rapids, Clearwater, Wabiskaw, McMurray, and Paleozoic Devonian Waterways Formations (Flach, P. D., 1984). Most Athabasca oil sand deposits exist in the Lower Cretaceous McMurray Formation (Conly et al., 2002). Clearwater Formation is a conformable and continuous stratigraphic unit that serves as the upper layer of the Lower Cretaceous Manville group. It is predominantly composed of shale and serves as the caprock for the underlying McMurray oil sands reservoir (Uwiera-Gartner et al., 2011). The Wabiskaw Member forms the basal unit of the Clearwater Formation. The McMurray Formation is the primary host of the Athabasca oil sands deposit, which was formed during the Lower Cretaceous period. The formation was deposited unconformably on top of the erosional surface of the Devonian Formation in a north-south trend (Flach & Mossop, 1985).

Rottenfusser et al. (1988) conducted a geological analysis of the AOSTRA UTF Phase A reservoir using well logs and core data, taking advantage of an extensive installed monitoring program. Based on their findings, the Wabiskaw sand member and McMurray Formation were subdivided into seven distinct stratigraphy from Units A through G, as schematically represented in Figure 1. These subdivisions were aimed at achieving a more detailed lithological characterization and enabling the interpretation of the petrophysical properties for each unit.

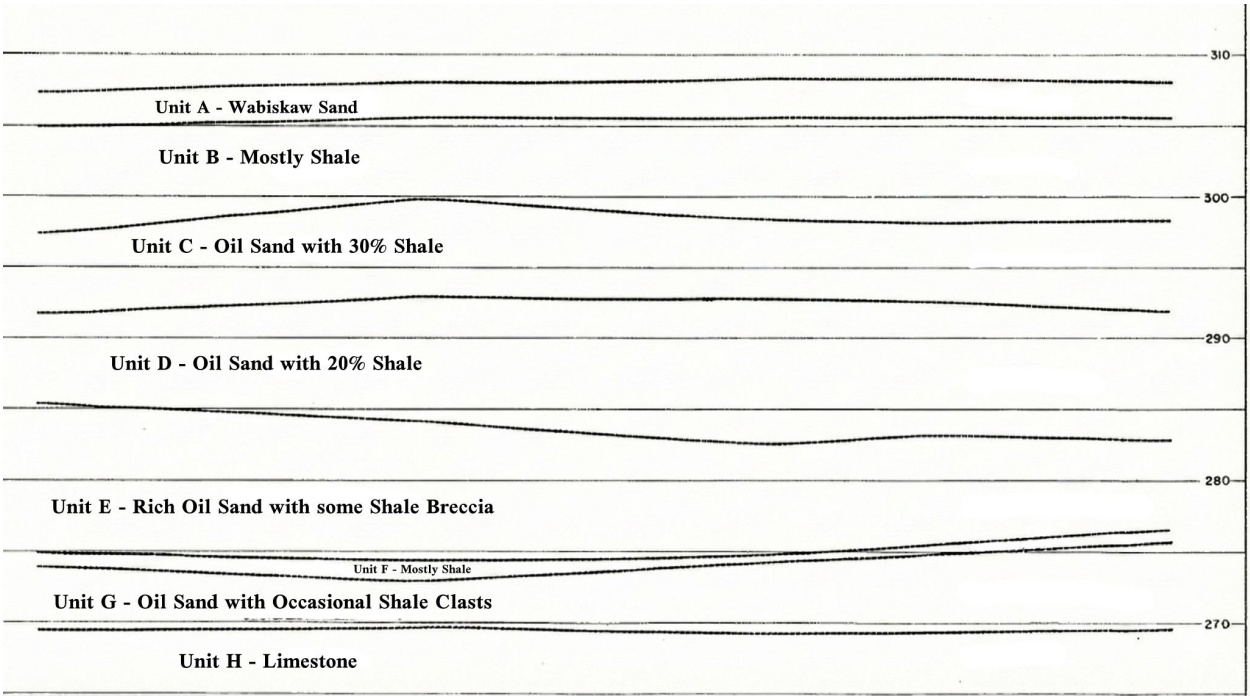


Fig. 1- Schematic Representation of the Stratigraphic Units at UTF Phase A.

Motivation

AOSTRA Underground Test Facility (UTF) Phase A is a highly instrumented SAGD pilot that provided unprecedented insights into the mechanism of the SAGD process. Installed instruments included temperature, pressure, inclinometer, and extensometer wells, with many of these concentrated on a geotechnical cross-section positioned midway along the three wellpairs. These instruments were used to monitor the change in temperature, pressure, and horizontal and vertical movements, allowing for measurements of thermal, hydraulic, and geomechanical responses in both the reservoir and underground tunnels. This comprehensive monitoring program created a unique opportunity to evaluate SAGD behavior and establish a baseline for further studies and analyses. Several studies were conducted by Siu et al. (1991), Chalaturnyk et al. (1991), and Li & Chalaturnyk (2005) on UTF to match different responses such as temperature and injection and production data. Nonetheless, certain geomechanical responses in UTF Phase A remain unresolved and have yet to be accurately history matched. In particular, responses such as vertical and horizontal strain in the reservoir were very challenging to history match for all previously developed models, likely due to their reliance on 2D simulations. This study generates a 3D geological model as the foundation for improving our understanding of the 3D response of the reservoir during the Phase A SAGD trials. This allows inclusion of tunnel response measurements and removal of 2D plane strain assumptions in the subsequent 3D reservoir geomechanical simulations. Accurate prediction of these responses is possible using more complex models with the help of sophisticated workflows and robust computational resources. The prediction of the responses can allow for a better understanding of SAGD process which can help in mitigating the risks associated with the process and boosting the confidence in SAGD simulations. As the main parts that all previous models lack were the effect of the third dimension and the underlying tunnel, incorporating both 3D modeling and tunnel effect can highly enhance the output of the simulation. These crucial elements require a reevaluation of the UTF Phase A and the creation of a 3D model that incorporates the underlying tunnels. This will establish a defensible process for constructing a precise 3D geocellular model of UTF Phase A that is suitable for future reservoir geomechanical simulations.

Results & Observations

The final facies model was generated using Sequential Indicator Simulation (SIS), a widely utilized technique for discrete logs. Figure 2 illustrates the final 3D facies model of UTF Phase A,

encompassing all stratigraphic units, specifically units A through G. Although the model was developed in three dimensions, all comparisons with previous interpretations were conducted in two dimensions using a specific cross section known as the geotechnical cross section. This geotechnical cross section, depicted in Figure 3, represents the highly instrumented segment in UTF Phase A and was employed in all prior studies and interpretations. Figure 4 provides a visual comparison of the lithofacies between the historical interpretations and the newly developed model. This visual comparison shows a high compatibility between both models which can boost the acceptance and the accuracy of the developed one.

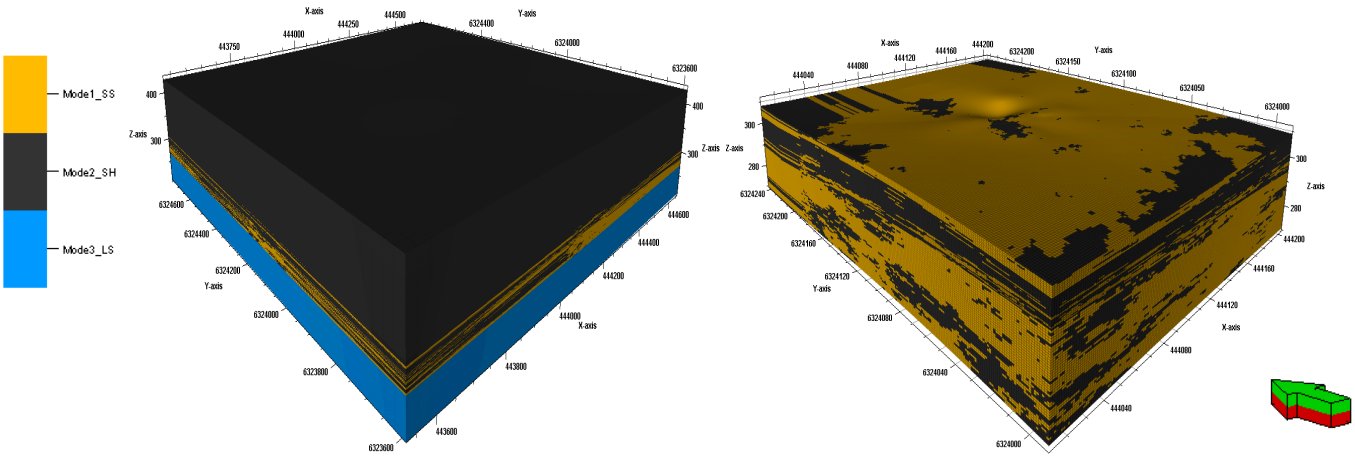


Fig. 2- Facies model: the final generated facies model for (a) the whole area and all zones; and for (b) the reservoir area only from Wabiskaw sand member to Devonian.

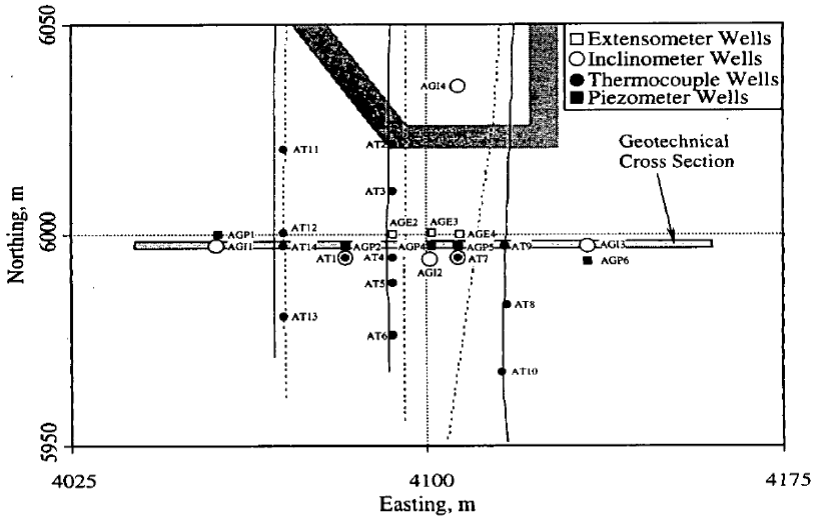


Fig. 3- Geotechnical Cross-Section at UTF Phase A.

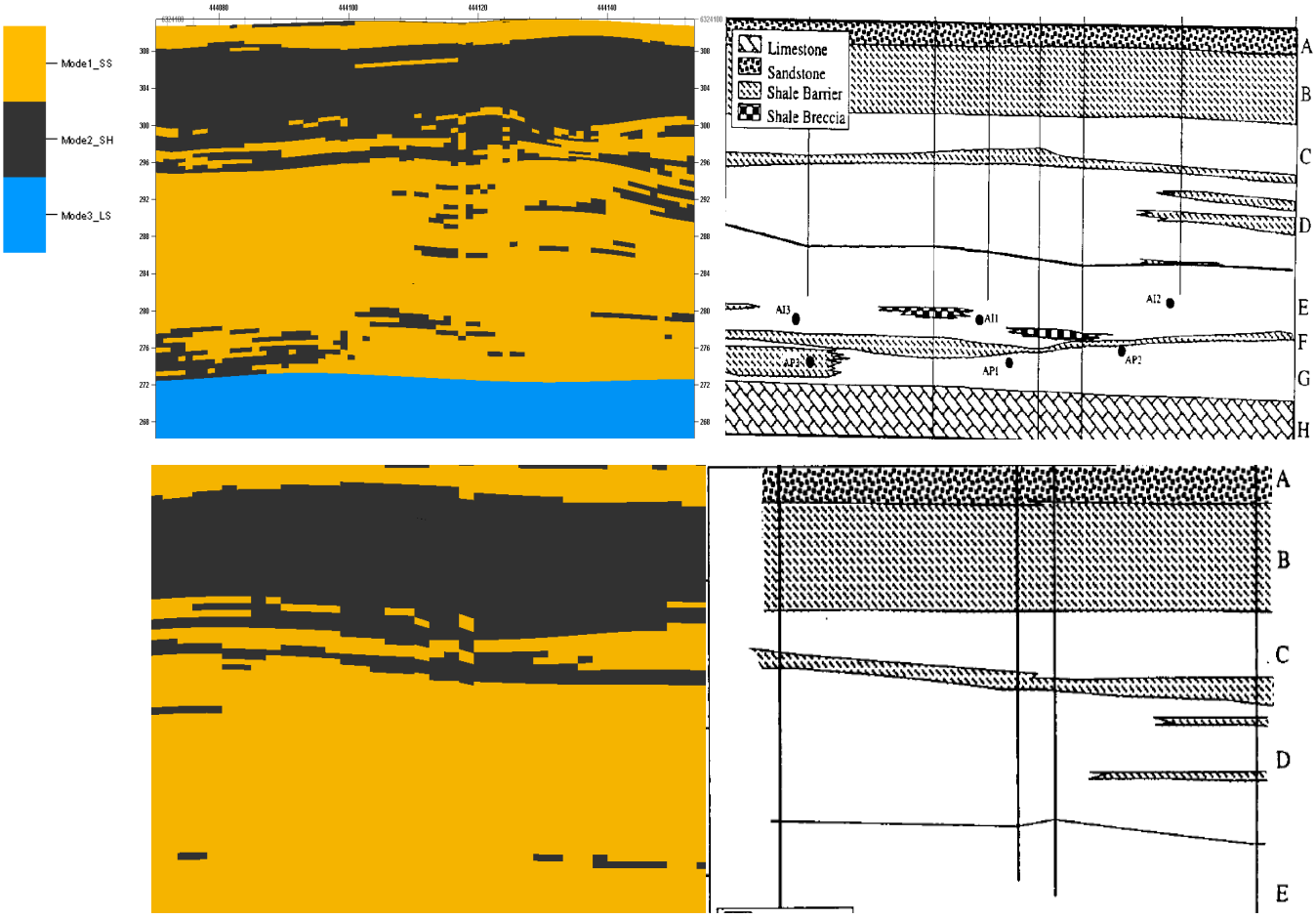


Fig. 4- Facies comparison between the new and previous models of the geotechnical cross section.

Summary

This model is crucial to have a foundational base model that can be used for other studies. The main purpose of developing this model is to use it for a future reservoir-geomechanical simulation. The reservoir geomechanical simulation will target history matching, for the first time, the 3D steam chamber growth from temperature measurements along with the deformation in the tunnel that underlying the steam chamber.

From Phase A to Phase B at the UTF

UTF Phase B stands out as one of the most comprehensively instrumented SAGD projects globally, offering a unique chance to deepen our understanding of the process and its underlying mechanisms. This phase includes approximately 30 wells equipped with temperature data, five wells with pressure data, two extensometers, three heave surveys, and initial and final

inclinometer surveys in over ten wells. Although there is ongoing debate about the significance of geomechanical effects in SAGD processes, and despite Phase B being less equipped in this regard compared to Phase A, it still boasts a substantial array of measurements in a large-scale operation. By analyzing Phase B data alongside 3-D sequentially coupled reservoir geomechanical modeling, we can evaluate the influence of geomechanics on the development and structure of the steam chamber. This will significantly enhance our understanding of geomechanical effects in SAGD and thermal heavy oil recovery.

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