geoconvention
Calgary • Canada • May 12-14 2025

De-Risking SAGD Operations Using Geochemical Tools: A Case Study in the Alberta Oil Sands

Norka Marcano[1], David Sprague[2]
[1]SLB
[2]Harvest Operations Corp.

Summary

The production of extra-heavy oil accumulated in Lower Cretaceous reservoirs in the Alberta Oil Sands is primarily accomplished by Steam Assisted Gravity Drainage (SAGD; Shen, 2013). This process can be negatively impacted by heterogeneities in rock petrophysical and fluid properties. The presence and extension of permeability barriers in the reservoir and higher saturation water zones can affect the development of the steam chamber, lead to heat loss and hinder oil drainage (Bai et al., 2024; Kumar, 2022). In this study, geochemical molecular fingerprinting of hydrocarbon extracted from McMurray and Wabiskaw reservoir rock samples is used to identify compositional gradients resulting from oil biodegradation, as a proxy to understand variations in the oil physical properties. The shape of these gradients also helps defining the presence of barriers and baffles to the fluid flow in vertical wells and their lateral extension, aiming at de-risking SAGD operations.

Theory and Method

The Alberta Oil Sands were formed by microbial alteration of conventional crude oil over geological timescale. This biodegradation process consists of a sequential removal of the more desirable components of oil (Head et al., 2003), conducive to a progressive deterioration of oil physical properties towards a denser, more viscous, oil. The resulting heavy and extra-heavy oil accumulations are characterized by large vertical and lateral compositional variations (Marcano et al., 2013). The shape of compositional gradients developed within oil columns and final oil quality are controlled by the relationship between biodegradation rates, fresh oil charge rate, diffusion of oil components towards the biodegradation zone and mixing of fresh and degraded oil (Larter et al., 2006). Gradients are further impacted by the presence of baffles and barriers to fluid flow, showing offsets that can help the identification of these geological heterogeneities through oil molecular fingerprinting.

Lower Cretaceous Wabiskaw - McMurray oil sand accumulations in the Athabasca region of the Alberta basin, focus of this study, are complex reservoirs consisting of fluvial, estuarine and marginal marine deposits associated with sea-level fluctuations. The occurrence of mudstones as, for example, Inclined Heterolytic Stratification (IHS), or filling abandoned channels, results in heterogenous reservoir rocks which, together with variations in fluid properties, poses challenges to the success of SAGD operations.

In this study, twenty-eight (28) vertical wells were investigated in the Southern Athabasca region (Fig. 1). The distribution of studied wells was planned so it allowed the assessment of the lateral extension of identified geological features based on well logs . A systematic sampling of oil sand core from top to bottom of pay zones was conducted. Samples were extracted with a polar solvent to recover bitumen for molecular analysis. The total hydrocarbon fraction of the extracted material was analyzed by Gas Chromatography-Mass Spectrometry (GCMS). A cocktail of internal

standards was used for absolute quantification of 186 compounds, including non-biomarker and biomarker saturated and aromatic hydrocarbons. Peak ratios were also calculated to obtain traditional oil source and thermal maturity parameters.

All analyses were performed on existing wells that have been stored unpreserved. The fact that the cores were not fresh, and not preserved, did not make any detectable difference to the usefulness of the GCMS analysis over the range of compounds of interest.

The primary use of the molecular data in this study has been to assess vertical reservoir continuity and evaluate whether intervals of non-reservoir seen on well logs or core photos are widespread barriers or local baffles. This information helps assess bitumen in place that should be accessible to SAGD development. The data have also been used to determine where development well pairs will be placed, to ensure that neither producers nor injectors are isolated by a barrier. Interpreted molecular data have been additionally used to understand well pair performance, and to plan remedial action for poorly performing well pairs.

Results and Conclusion

Unresolved complex mixtures, or humps, are observed on the total ion chromatograms of all investigated samples, with superimposed biomarkers (Fig. 2a). Normal and isoprenoid alkanes are completely removed, and polycyclic aromatic hydrocarbons (PAH) are altered to varying degrees. This indicates the studied sample set is severely biodegraded to at least level PM5 (Peters and Moldowan, 1991), as previously reported for the study area (see Marcano et al., 2013).

Molecular ratios based on saturated and aromatic hydrocarbons demonstrate samples are genetically related, with similar level of source rock thermal maturity corresponding to an early stage of oil windows of petroleum generation (VRo equivalent ~0.5%, based on Ts/Ts+Tm).

Clear concentration gradients are identified for polycyclic aromatic hydrocarbon and sulfur aromatic compounds (Fig.2b, Fig. 3a-c), with concentrations dropping from hundreds to a few tens of ppm from top to bottom of sampled intervals. These compound families are deemed good proxies for biodegradation level and progressive changes in oil quality in most investigated wells. Although not investigated in this study, it is expected that viscosity follows similar trends.

Figure 3 shows comparisons of concentration profiles with well logs of selected wells under various scenarios. In Fig. 3a, a large offset in molecular gradients of biodegradation-sensitive compounds confirms an expected barrier related to a mud plug. Meanwhile, a smooth trend in the main reservoir section indicates other muddy intervals, interpreted as breccia and dune mud, do not impact reservoir communication. This latter case is also observed in the examples of Figs. 3b and 3c.

The IHS identified at the base of the main reservoir (massive sand) corresponds to a small disturbance on the concentration profile trends of PAH in Fig. 3b, which is interpreted as a baffle. In contrast, molecular data in Fig. 3c indicates that this IHS in a neighboring well is identified as a barrier to the fluid flow, based on the separate trends observed in the molecular composition gradients. In general, barriers are only observed in part of one of the pads.

Overall, molecular composition data provides a tool to support reservoir characterization in the investigated severely biodegraded accumulation in the Athabasca area, with the purpose of

derisking SAGD operations. It allows to distinguish baffles from barriers in cases in which the information from well logs is not conclusive, as well as confirm barriers and define their lateral extension. The data also supports well placement and its performance assessment. Variations in absolute concentrations are associated with ranges in viscosity values, providing a tool to evaluate changes in mobility. The developed compositional baseline can additionally be used in a future development phase for SAGD operations surveillance.

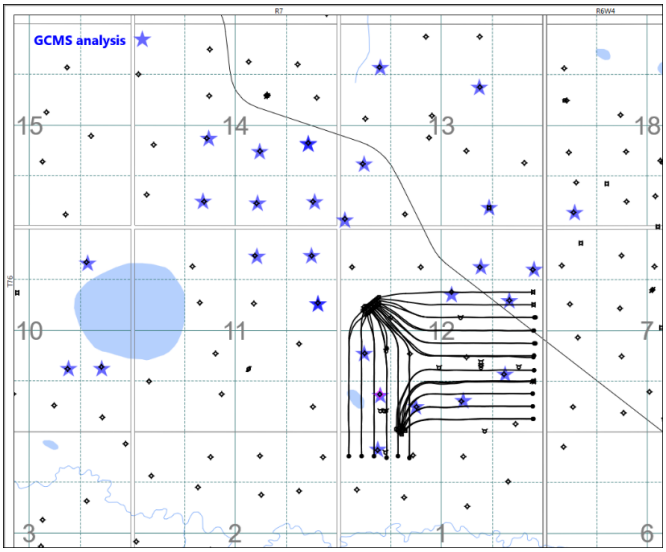

Figure 1: Areal distribution of the investigated wells.

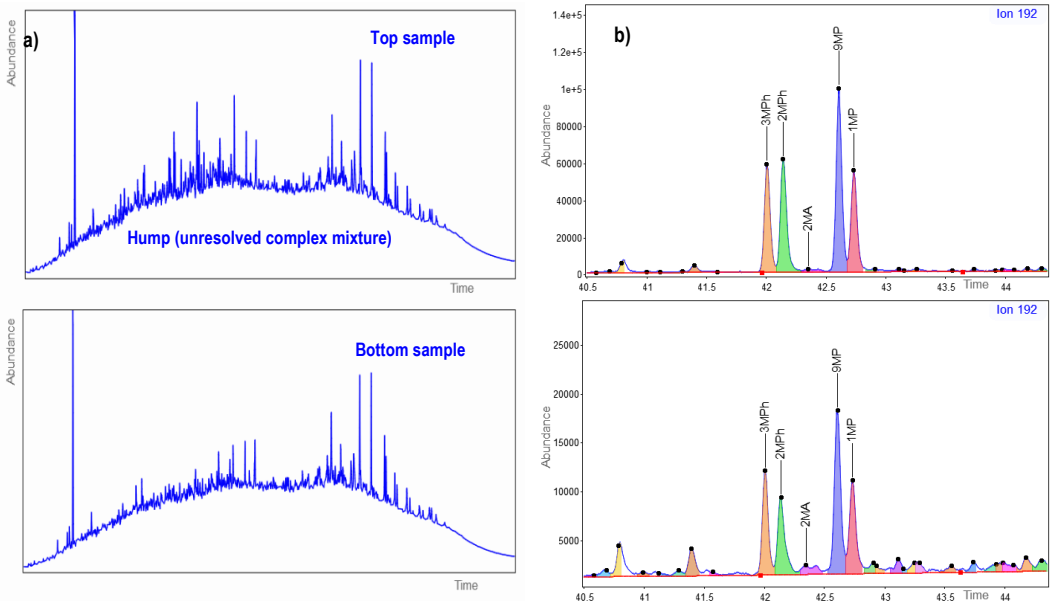

Figure 2: a) Partial reconstructed total summed mass chromatograms representing the total hydrocarbon fraction and b) Ion m/z 192 of methylphenanthrenes, in representative top and bottom samples from an investigated oil column.

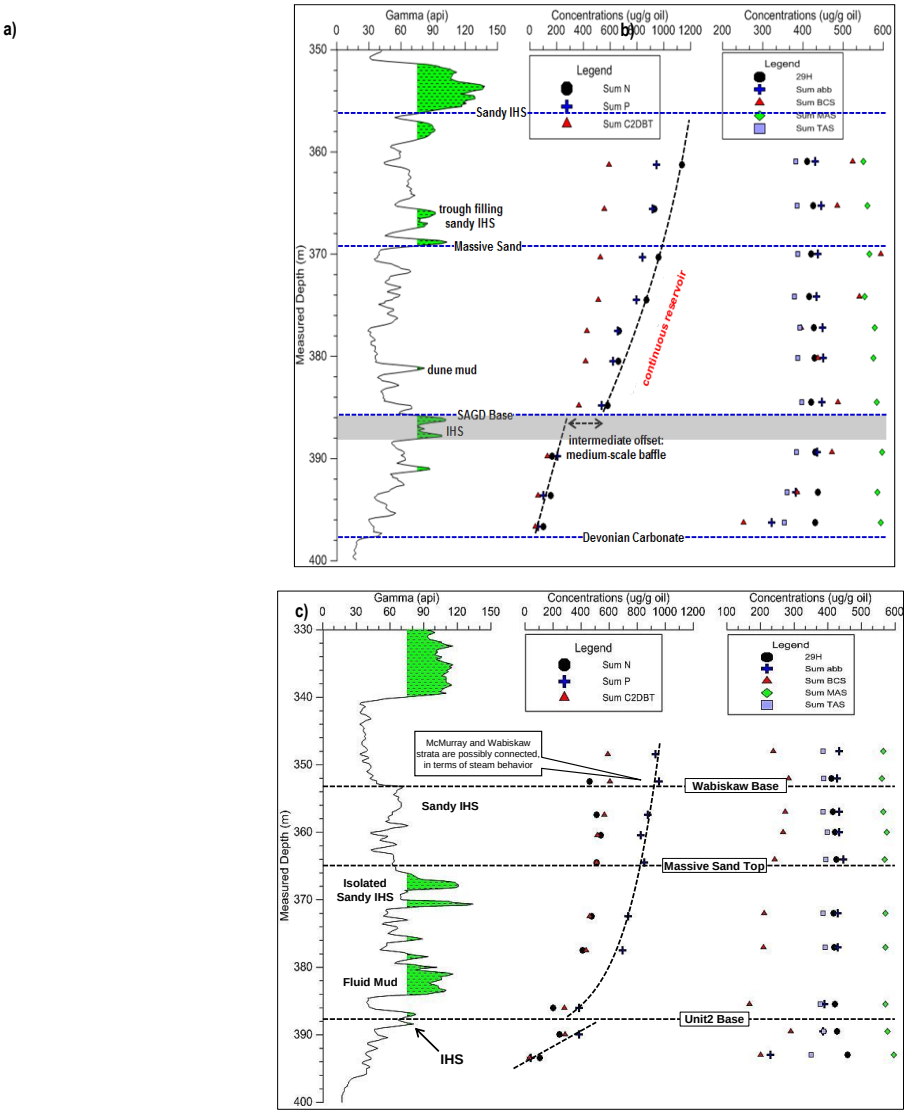

Figure 3: Selected examples of the comparison of molecular concentration profiles with interpreted well logs

Acknowledgements

We thank Harvest Operations Corp. for allowing the presentation of these data.

References

Bai, Y., Bin Wang, B., Zhan, S., Zhang, L., Taichao Wang, Yan Sun, Wenbo Zhang, 2024. Impact of Shale Barriers on Steam Chamber Evolution and Heat Distribution during the Rising Stage of Steam-Assisted Gravity Drainage (SAGD). ACS Omega 10 (1),1839–1852

Head, I.M., Jones, D.M., Larter, S.R., 2003. Biological activity in the deep subsurface and the origin of heavy oil. Nature 426, 344-352.

Kumar, A. 2022. Impact of shale barriers on SAGD and ES-SAGD performance. Master's thesis, University of Calgary, Calgary, Canada. Retrieved from https://prism.ucalgary.ca.

Larter, S., Huang, H., Adams, J., Bennett, B., Jokanola, O., Oldenburg, T., Jones, M., Head, I., Riediger, C., Fowler, M., 2006. The controls on the composition of biodegraded oils in the deep subsurface: Part II - Geological controls on subsurface biodegradation fluxes and constraints on reservoir-fluid property prediction. AAPG Bulletin 90, 921-932.

Marcano N., Larter S., Mayer B., 2013. The impact of severe biodegradation on the molecular and stable (C, H, N, S) isotopic compositions of oils in the Alberta Basin, Canada. Organic Geochemistry 59, 114-132.

Peters, K.E., Moldowan, J.M., 1993. The Biomarker Guide: Interpreting Molecular Fossils in Petroleum and Ancient Sediments. Prentice Hall, Englewood Cliffs, New Jersey, 363pp.

Shen, C. 2013. *SAGD for Heavy Oil Recovery in Enhanced Oil Recovery Field Case Studies*. James J. Sheng Ed., Gulf Professional Publishing, 413-445