A Predictive Approach for Tight Oil and Gas Exploration*

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Search and Discovery Article #42028 (2017)**
Posted March 27, 2017

*Adapted from extended abstract based on poster presentation given at AAPG Hedberg Conference, The Future of Basin and Petroleum Systems Modeling, Santa Barbara, California, April 3-8, 2016

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Abstract

This paper presents an integrated approach to study tight oil/gas sweet spots with petroleum systems modeling and integrates seismic inversion results with petroleum systems modeling (PSM) to capture the major controls of the tight oil/gas trapping mechanisms. The Petroleum Systems approach takes into account hydrocarbon generation, migration, and accumulation history of the deltaic system, considering buoyancy forces, formation pressures, capillary pressures, and permeabilities of each lithology through geologic history. Based on the PSM study, the tight oil/gas trapping mechanism is better understood. The systems need to be carefully assessed based on the type of target, considering factors, which can be positive for conventional targets or can be negative for unconventional targets. Improving high-resolution lithofacies and properly modeling the petroleum systems by applying advanced geophysical workflows are essential requirements to construct petroleum system models, which provide better understanding and predictions in these plays.

Introduction

This paper presents an integrated approach to study tight oil/gas sweet spots with petroleum system modeling. The final delivery of the study is a geological model with real predictivity for potential drilling candidates. Tight oil/gas plays are usually considered as large lateral continuous oil accumulations with low water saturation, no gas cap or downdip water contact (Pedersen et al., 2013), without the requirement of a structural trap in deep basin. Tight gas typically occurs in low porosity (<10%) and low permeability (in microdarcy range) reservoirs immediately adjacent to source rocks (Chapin et al., 2014, Guo, 2012).

Previous Work

Various approaches had been applied to tight oil/gas play researches. Petroleum system modeling has been used to analyze tight gas charging (Guo, 2012). Sequence stratigraphic analysis and seismic reservoir characterization are often used to explore for tight oil/gas sweet spots and drilling targets (Lupo and Krystinic, 2015) in complex depositional environments, unevenly distributed pay zones, and with unpredictable water production. Combined methods of petrology, fluid inclusion, petrophysics, sedimentology and basin modeling study have been conducted to determine geologic controls on reservoir quality (Tobin et al., 2010). However, there is currently no integrated approach of a geophysical study (for example, AVO inversion) with petroleum system modeling to improve understanding and predictions in these play types.

Although diagenesis play an important role in some of the tight reservoirs across the world, lithofacies variations controlled by depositional environments and compaction during geological subsidence still are the top two factors controlling reservoir quality of tight oil/gas resources (Chapin M. Et al., 2014, Vavra et. AL., 1991, Surdam et al., 1997). Additionally, the connectivity of porous sand bodies significantly controls hydrocarbon migration pathways and accumulations, not only for conventionals, but also for unconventionals. Pressure regime significantly impacted by lithofacies distribution also play an important role for a prospecting trap of tight oil/gas reservoirs (Surdam et al., 1997).

Methods

This study integrates seismic inversion results with petroleum system modeling (PSM) to capture the major controls of the tight oil/gas trapping mechanisms discussed above. A 3D geological model is populated by a lithology cube obtained from prestack stochastic seismic inversion data. The lithology model reflects all available well data and geological understanding of the area, a pro-delta/delta front system, which is characterized by sandstone/siltstone/shale laminations vertically and sandstone/siltstone/shale interfingering laterally (Figure 1). The compaction properties are taken from a standard database. Measured capillary pressure and porosity data are used for model calibrations. The Petroleum Systems approach takes into account hydrocarbon generation, migration, and accumulation history of the deltaic system, considering buoyancy forces, formation pressures, capillary pressures, and permeabilities of each lithology through geologic history.

Discussion

The target tight oil reservoirs were charged by the interfingering delta front and/or underlying pro-deltaic shales. Connectivities between porous sand/sandy bodies is one of the most critical factors controlling hydrocarbon migration and accumulation. They are the migration paths for the charge of conventional accumulations in structural highs, however, isolated stacked sand/sandy bodies could also be sweet spots of unconventional plays in deeper parts of a basin if properly charged.

It is not easy to understand and describe the effects of sand/sand body's connectivities in such complex lithofacies distribution system. PSM appears to be the only method to handle this challenge with help of numerical simulation. In addition, a model with more realistic lithofacies distributions enables better pressure and hydrocarbon distribution predictions. The predicted liquid hydrocarbon saturation by the PSM study successfully matched the typical tight oil play concept, which is located in deeper areas in the basin, is not structurally dependent, and lies adjacent to source rocks, etc. (Figure 2).

Results

Based on the PSM study, the tight oil/gas trapping mechanism is better understood. The sweet spot area of tight oil is mainly controlled by the following factors: 1) Isolated sand/sandy bodies in the deep basin; 2) Closely association with source rocks (short migration distance); 3) Well-developed porous bodies connecting kitchen areas to structural highs. These types of lithology bodies could also be excellent conduits for conventional accumulations, which is however beyond of scope of this study. The systems need to be carefully assessed based on the type of target, as factors, which can be positive for conventional targets and vice versa can be a disadvantage for unconventional targets. Improving high-resolution lithofacies and property modeling in petroleum systems models by applying advanced geophysical workflows is an essential requirement to construct PSM models, which provide better understanding and predictions in these plays.

Selected References

Chapin, M.A., J.K. Bobich, G.P. Diomampo, H.L. Schiller, S.M. Hurd, N.W. Brandon, G. Ugueto, and C.H. Fleming, 2014, Integrated static and dynamic modeling of the Pinedale tight gas field, Wyoming: in M. Longman, S. Kneller, T. Meyer, and M. Chapin, eds., Pinedale field: Case study of a giant tight gas sandstone reservoir: AAPG Memoir 107, p. 497–531.

Guo, Q., X. Li, C. Zou, J. Hu, and N. Chen, 2012, Predicting the distribution of the tight sandstone gas in the Hechuan play, Sichuan Basin, China: Bulleting of Canadian Petroleum Geology, v. 60/3, p. 186–199.

Lupo, T., and L. Krystinik, 2015, Exploring for Tight Oil in the Pennsylvanian Cleveland Sandstone on the Nemaha Uplift Using High-Resolution 3D Seismic and Stratigraphic Analysis: A New “Resource” Play Model? Tulsa Geological Society luncheon Meeting, Search and Discovery Article 10759, Web Accessed February 25, 2017, http://www.searchanddiscovery.com/documents/2015/10759lupo/ndx_lupo.pdf.

Pedersen, P.K., J.D. Fic, and A. Fraser, 2013, Integrated Geological Reservoir Characterization of the Cardium Light Tight Oil Play, Pembina Field in Alberta: Unconventional Resources Technology Conference, Denver, Colorado, 12-14 August 2013: pp. 807-813. doi: 10.1190/urtec2013-085

Surdam, R.C., 1997, A new paradigm for gas exploration in anomalously pressured “tight gas sands” in the Rocky Mountain Laramide Basins: in R.C. Surdam, ed., Seals, traps, and the petroleum system: AAPG Memoir 67, p. 283–298.

Vavra, C.L., M.H. Scheihing, and J.D. Klein, 1991, Reservoir Geology of the Taylor Sandstone in the Oak Hill Field, Rusk County, Texas: Integration of Petrology, Sedimentology, and Log Analysis for Delineation of Reservoir Quality in a Tight Gas Sand: Reservoir Characterization and Modeling: AAPG special volume 26, The Integration of Geology, Geophysics, Petrophysics and Petroleum Engineering in Reservoir Delineation, Description and Management, p. 130-158.

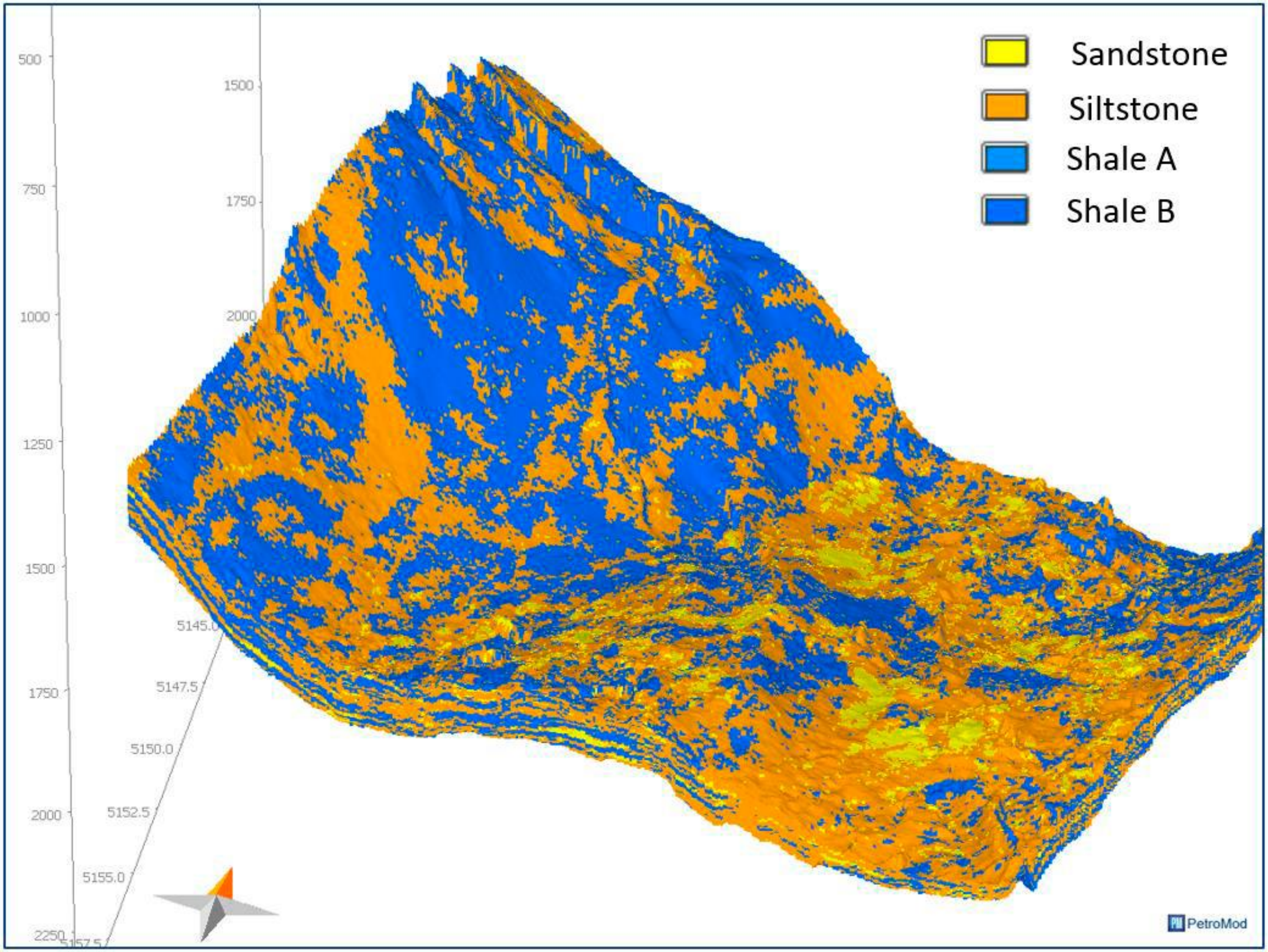

Figure 1. 3D Lithology distribution of PSM model derived from prestack stochastic seismic inversion data. Real data based lithofacies are used for PSM, instead of synthetic facies polygons for facies assignment in PSM traditionally.

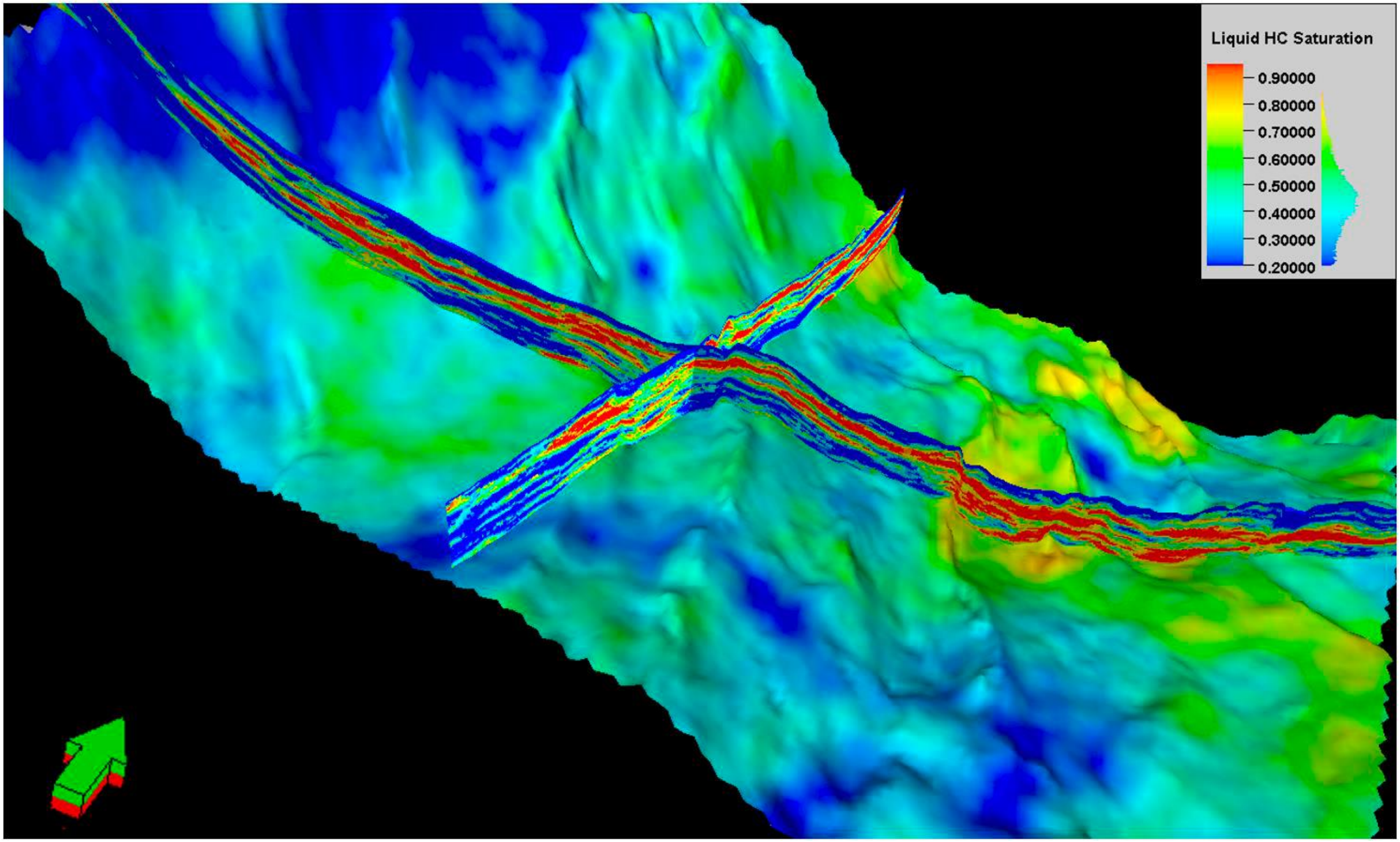

Figure 2. Predicted 3D hydrocarbon saturation simulated using petroleum systems modeling software. The background map is average liquid saturation of target tight oil reservoir layer. Two sections show detailed saturation sweet spots of liquid hydrocarbons.