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Exploration Paradigm Shift: The Dynamic Petroleum System Concept

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Abstract
Historically, exploration programs focused on finding subsurface traps. However, an effective trap is only one requirement for petroleum accumulations to exist. A static view of traps on a play fairway map ignores the fact that petroleum systems consist of many dynamic elements and processes that control whether present-day traps are barren or filled with oil and gas. This paper describes recent advances in software that link the distinct methodologies of basin modeling and petroleum system modeling, resulting in a paradigm shift from static to dynamic exploration methods.

Zusammenfassung
Früher fokussierte die Exploration auf das Auffinden von Fallen. Das Vorhandensein einer Falle ist jedoch nur eine Voraussetzung für Anreicherungen von Kohlenwasserstoffen. Eine rein statische Betrachtung von Fallen eines Ölfeldes ignoriert die Tatsache, dass Kohlenwasserstoffsysteme zahlreiche dynamische Elemente und Prozesse umfassen. Diese kontrollieren, inwieweit heutige Fallen unproduktiv oder mit Öl und Gas gefüllt sind. Der vorliegende Artikel beschreibt jüngste Software-Fortschritte, welche bestimmte Methoden der Beckenmodellierung mit der Modellierung von Kohlenwasserstoffsystemen verknüpft. Damit wird ein Paradigmenwechsel von statischen zu dynamischen Explorationsmethoden herbeigeführt.

1. Introduction

The petroleum system concept becomes important when deep burial of source rock yields thermogenic oil and/or gas (also called hydrocarbons). A petroleum system consists of four essential elements (source, reservoir, seal, and overburden rock) and two processes (trap formation and generation-migration-accumulation; Magoon & Dow 1994). Petroleum systems occur in sedimentary basins, but not all sedimentary basins contain petroleum systems. To quantify petroleum systems, one must first model basin geohistory. Basin modeling applies mathematical algorithms to seismic, stratigraphic, paleontological, petrophysical, well log, and other geologic data to reconstruct the deposition and erosion of rock layers through space and time. The goals of this paper are to [1] clarify the difference between basin modeling (rocks) and petroleum system modeling (hydrocarbon fluids), [2] illustrate the workflow for basin and petroleum system modeling (BPSM) studies, and [3] provide examples of how this systematic process reduces exploration risk.

2. BPSM Workflow

BPSM computations require a conceptual model of basin history that is subdivided into an uninterrupted sequence of events in space and time (e.g., deposition or erosion of strata). Conceptual models range in complexity depending on available data. For example, in poorly explored areas a simple sketch of basin stratigraphy and architecture in two or three dimensions (2D or 3D) is

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a worthwhile starting point. A 2D model based on a geologic type section or a 3D model based on subsurface maps from seismic data might be constructed to capture a geologic interpretation of the study area. Even in frontier areas where source rocks have not been identified, BPSM is a powerful predictive tool because knowledge of the depositional environments in the stratigraphic succession can be used to infer the quality of source rock units and the amounts and compositions of the generated petroleum (e.g., Klemme & Ulmishek 1991).

Model simulations are performed on discretized numerical representations of the geologic and geochemical data, i.e., grid cells having constant property distributions within each cell. Geologic processes are recreated from past to present in a process called «forward deterministic modeling» using inferred starting conditions (Fig. 1). Numerical values are required for all input parameters in the figure. Input data include gridded surfaces of buried rock units from seismic and well log interpretations, ages of units, lithology and physical properties such as thermal conductivity, porosity, and permeability, and boundary conditions, including present and past basal heat flow and surface or sediment-water interface temperatures that are corrected for present and past water depth. Geochemical data, such as the type and amount of organic matter in the source rock and the kinetics for conversion of the organic matter to petroleum, are also required.

The North Slope of Alaska provides an example of a mega-regional study area (Fig. 2)

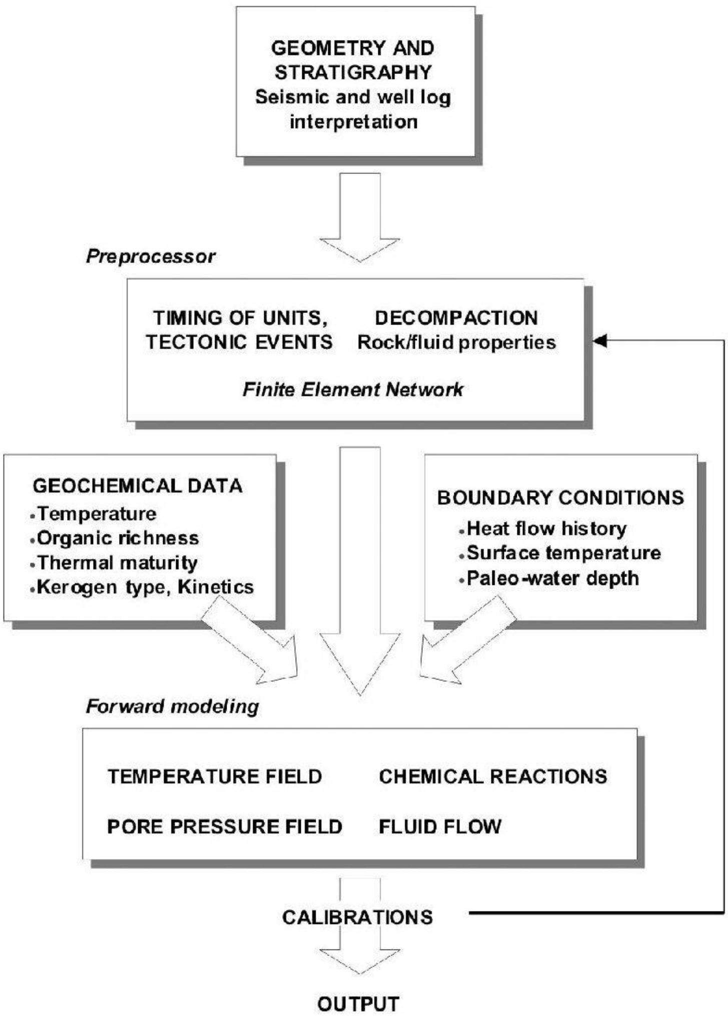

Fig. 1:
Process workflow diagram for basin and petroleum system modeling (from Peters et al. 2008).

where seismic data were used to create a 3D cube of present-day geometry (Fig. 3). Forward deterministic computations simulate the burial history of the rock units and the generation-migration-accumulation of petroleum within the 3D cube through time (e.g., Hantschel & Kauerauf 2009). For example, forward modeling requires that each rock unit be decompacted to restore its properties prior to deposition of overlying units. A key dynamic aspect of the 3D North Slope model is that it accounts for progradation of the time-transgressive Cretaceous-Tertiary Brookian Sequence on the Lower Cretaceous Unconformity (LCU, Fig. 3). These overburden rocks control the timing of generation from underlying source rocks, which were identified by geochemical oil-source rock correlation and carefully mapped using seismic and well log data (Peters et al. 2006, 2007). For example, Fig. 4 predicts the fractional conversion of organic matter to petroleum (transformation ratio) in the pre-LCU Triassic Shublik Formation source rock due to thermal maturation. Model output, such as predicted temperature, thermal maturity of organic matter, pressure, or porosity, can be compared to measured data from available wells. The model can be calibrated to improve the match between the simulation results and measured data. Finally, models can be processed in a stochastic framework to quantify uncertainties and determine correlations and risks.

3. Timing of Petroleum System Events

BPSM offers a clear advantage over play fairway maps because it accounts for the risk posed by the timing of generation-migration relative to trap formation. Both charts in Fig. 5 are based on thermally mature Triassic Shublik Formation source rock in deep areas off structure. At Prudhoe Bay and elsewhere on the Barrow Arch, trap formation preceded generation-migration by several million years, resulting in major oil accumulations (modified from Bird 1994). However, the events chart for the Brooks Range foothills in south-central NPRA (~153-158° W longitude) shows that timing risk is high for the structural traps, which can only be filled by re-migration of petroleum from older stratigraphic traps, as postulated to occur in turbidite sandstones near the base of the Brookian Sequence. Timing of generation-migration relative to trap formation is favor-

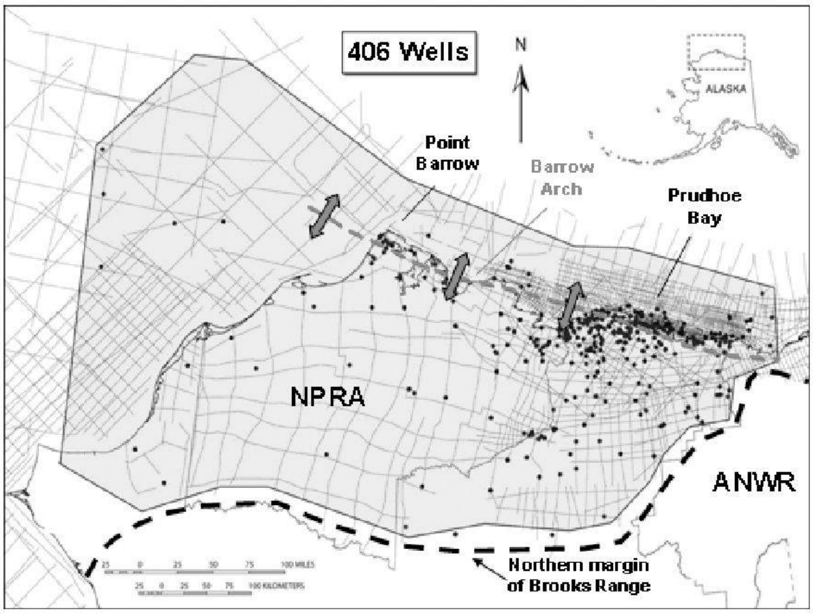

Fig. 2:
Alaska North Slope study area (gray shading; 832 × 520 km with a model grid cell spacing of 1 km) includes seismic lines (gray) and wells (dots) used to construct structure and isopach maps. The Barrow Arch is a broad east-plunging anticlinal trend that trapped abundant petroleum, as at Prudhoe Bay Field. NPRA = National Petroleum Reserve in Alaska, ANWR = Arctic National Wildlife Refuge.

able for the stratigraphic traps, although there is significant risk associated with migrating petroleum from the source rock upward through ~2000 ft (~610 m) of Jurassic and Lower Cretaceous mudstone into the turbidite sandstones.

The dynamic BPSM perspective provides management with a competitive edge over that based on the static view of petroleum occurrence. As another example, fairway mapping in a proprietary study area defined northern and southern fold belts, both containing abundant traps. Because of shallower water and thus less expensive drilling, the operator was inclined to drill the northern fold belt first. However, BPSM clearly showed that traps in the northern fold belt did not form until after generation and migration of petroleum from the source rocks. Because the traps were absent at the time of petroleum migration, the northern fold belt lacked significant accumulations and drilling results were disappointing. However, BPSM for the southern fold belt showed that trap formation occurred prior to generation-migration-accumulation. The modeling convinced the operator that the southern fold belt is the more favorable exploration target, as validated by recent exploration results.

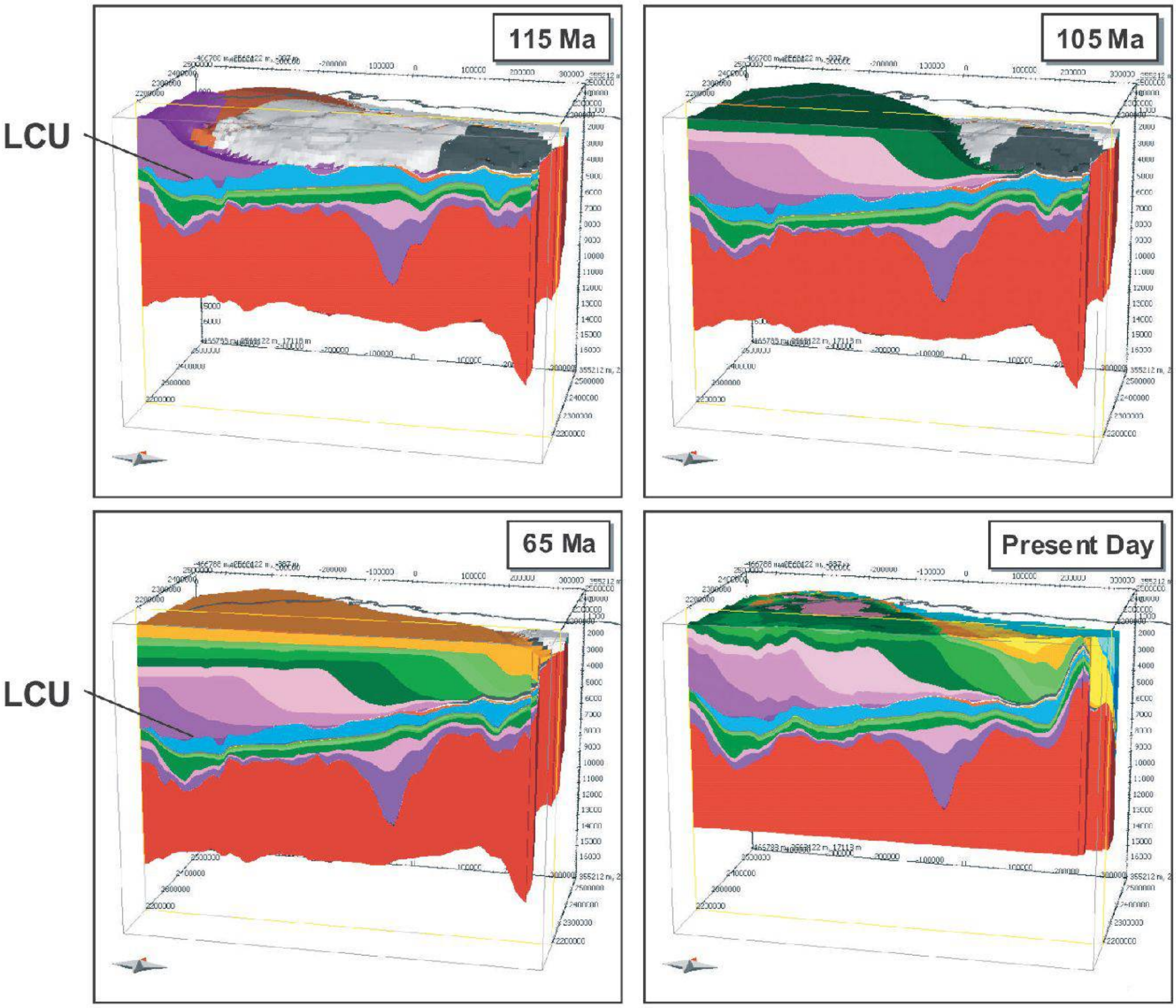

Fig. 3: Four time slices from a 3D BPSM model show the dynamic progradation of Brookian Sequence foresets from southwest to northeast across the North Slope of Alaska, which controlled the timing of petroleum generation from source rocks below the Lower Cretaceous Unconformity (LCU) as shown in Fig. 3. Coastline is black.

4. Conclusions and Future Plans

Basin modeling differs from petroleum system modeling because it deals with rocks rather than fluids. Basin modeling uses mathematics to reconstruct the geohistory of rocks, including the deposition and erosion of strata through space and time. Petroleum system modeling begins after creation of the basin model and when effective source rock exists in the basin. Once petroleum is generated, the focus of the modeling shifts from rocks to fluids (oil and gas). Petroleum system modeling reconstructs the evolution of petroleum and is a powerful predictive tool in exploration.

BPSM has become the technology centerpiece for many integrated exploration companies because it reduces exploration risk by incorporating a broad spectrum of geoscience data from seismic measurements, well logs, stratigraphy, geothermics, structural geology, micropaleontology, and geochemistry. It can be used to quantify many of the key aspects of evolving petroleum systems to understand and predict the locations, volumes, compositions, and pressure-volume-temperature properties of petroleum accumulations. Virtually all major oil companies independently recognize the need for basin and petroleum system models (Peters 2009) because they:

1] organize data, allowing deficiencies or inconsistencies to be identified,

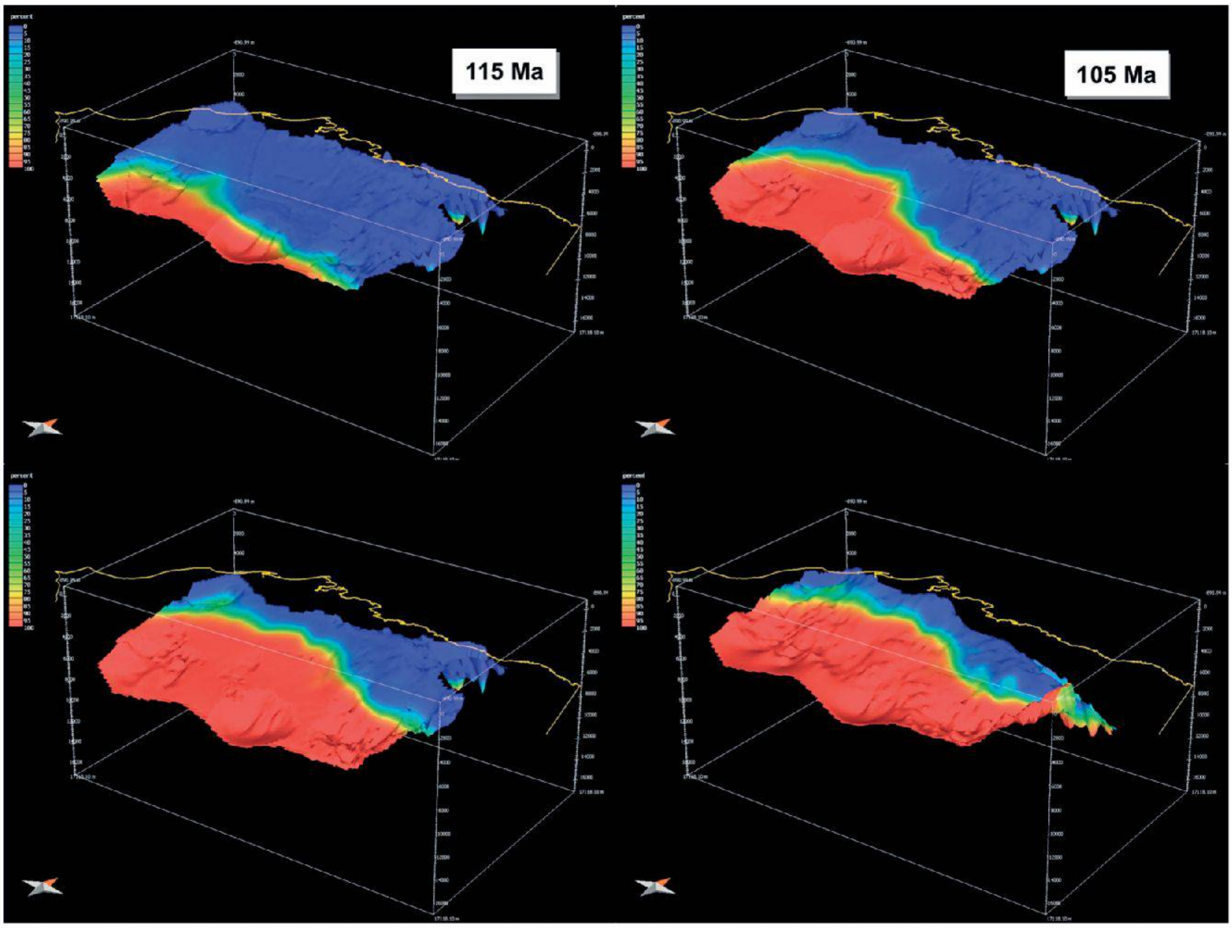

Fig. 4: Calculated fractional conversion (blue = 0%, red = 100%) of organic matter to petroleum in the Triassic Shublik Formation source rock at four different times on the Alaska North Slope. The Shublik Formation is located below the Lower Cretaceous Unconformity and the Brookian Sequence in Fig. 2. Coastline is yellow.

2] archive data (data loss due to personnel attrition and reorganization is a major cost factor),
3] depict the essential risk elements (source, reservoir, seal, and overburden) and processes (trap formation and generation-migration-accumulation) through geologic time and thereby enhance communication with stakeholders,
4] convert static data into dynamic processed data and interpretations that can be used to assess the range of possible outcomes, and
5] provide a consistent approach to compare and evaluate prospects.

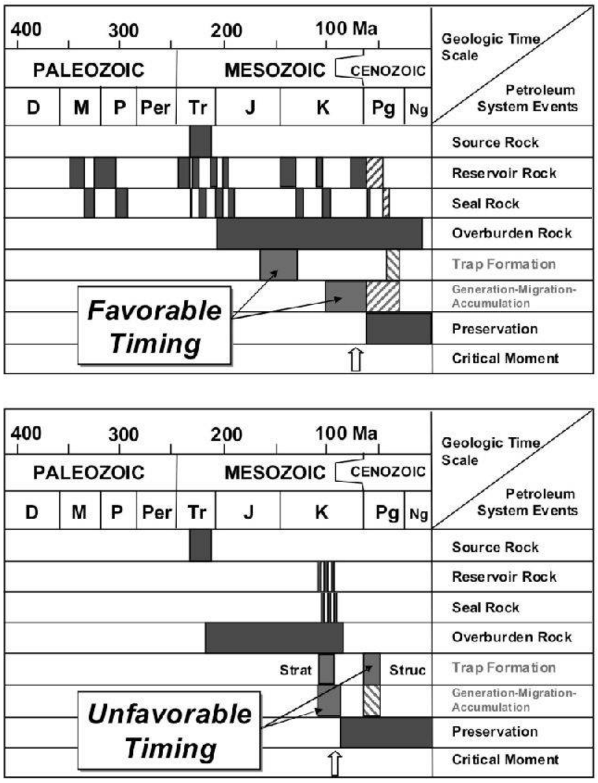

Fig. 5: Petroleum system events chart for the Shublik-Ivishak(!) petroleum system (modified from Bird 1994, Peters et al. 2005) near Prudhoe Bay oil field (top) and the foothills of the Brooks Range in south-central NPRA (bottom). Vertical arrows identify the critical moment, which is the time that best depicts the generation-migration-accumulation of petroleum (Magoon & Dow 1994). Hatched symbols indicate westward migration of accumulated petroleum due to regional tilting of the Barrow Arch (top) and re-migration due to Tertiary deformation in the foothills (bottom).

Accurate predictions of volumes and compositions of petroleum accumulations will benefit from further study, particularly related to calibration. Most models are calibrated using corrected bottom-hole temperatures and vitrinite reflectance. In the future, it is likely that more compositional kinetic models will be calibrated using measured reservoir pressures and compositions of reservoir fluids. This will also require further development of algorithms to address secondary processes that affect petroleum composition, including biodegradation, thermal cracking, and thermochemical sulfate reduction. Simulation of fluid migration through faults is a topic of much needed research, as most current models treat fault behavior as input. For example, faults can be designated as open or closed during various time intervals to test their effect on simulation results. Deterministic models need to be developed that predict evolving fault behavior with respect to migrating fluids and this is being addressed by close links between petroleum system and geomechanics simulators. This goal can only be achieved by parallel development of viable 3D rock movement simulators.

Probably the most important current development efforts in BPSM software are aimed to improve workflows by tightly integrating them with industry standard data handling software. This enables the construction of input models that better account for the available data and allow the results to be more easily calibrated and analyzed using the entire range of exploration data. These workflows facilitate integration of mega-regional to prospect scale models using another current key development, local grid refinement (LGR). For example, LGR data models can used to include reservoir or seismic scale data in mega-regional-scale petroleum system studies. Thus, multiphase flow processes can be fully simulated within a mega-regional-scale model, which can then be linked to a reservoir-scale model. This approach has been used to understand and predict heavy oil distributions in a milestone study of a major oil field in the Middle East. Additional refinements include the ability to simulate processes in the most complex tectonic environments by linking petroleum system modeling directly to structural modeling.

Energy is the lifeblood of economic prosperity. Limited alternatives to the convenience and energy content of petroleum guarantees that the search for additional oil and gas resources will continue for many decades. Because it has become an indispensible tool for exploration, BPSM technology is now employed by the major service providers for industry. Software development continues to accelerate. It is expected that BPSM will play an increasingly vital role in exploration, similar to the now indispensable role of reservoir modeling in production.

Acknowledgments

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References

Bird, K. J. 1994: Ellesmerian(!) petroleum system, North Slope, Alaska, U.S.A. In: Magoon, L. B. & Dow, W. G. eds.: The petroleum system – from source to trap., p. 339-358.

Hantschel, T. & Kauerauf, A. I. 2009, Fundamentals of basin and petroleum systems modelling. New York, Springer, 476 p.

Klemme, H. D. & Ulmishek, G. F. 1991: Effective petroleum source rocks of the world: stratigraphic distribution and controlling depositional factors. AAPG Bulletin 75, 1809-1851.

Magoon L. B. & Dow, W. G. 1994: The petroleum system. In: Magoon, L. B. & Dow, W. G. eds.: The petroleum system – from source to trap. AAPG Memoir 60, 3-24.

Peters, K.E., Lampe, C., Bird, K. J. & Magoon, L. B. 2005: 4-D modeling of the Shublik-Ivishak(!) petroleum system, North Slope, Alaska. Joint Meeting Pacific Section, AAPG & Cordilleran Section, Geological Society of America, April 29 - May 1, 2005, San Jose, California, Paper 40-4, Geological Society of America, Abstracts with Programs 37, p. 93; http://gsa.confex.com/gsa/2005CD/finalprogram/abstract_85375.htm.

Peters, K.E., Magoon, L. B., Bird, K. J., Valin, Z. C. & Keller, M. A. 2006: North Slope, Alaska: source rock distribution, richness, thermal maturity, and petroleum charge. AAPG Bulletin 90, p. 261-292.

Peters, K.E., Ramos, L. S., Zumberge, J. E., Valin, Z. C., Scotese, C. R. & Gautier, D. L. 2007: Circum-Arctic petroleum systems identified using decision-tree chemometrics. AAPG Bulletin 91, p. 877-913.

Peters, K. E., Magoon, L. B., Lampe, C., Hosford Scheirer, A., Lillis, P. G. & Gautier, D. L. 2008: A four-dimensional petroleum systems model for the San Joaquin Basin Province, California: in Hosford Scheirer, A., ed.: Petroleum systems and geological assessment of oil and gas in the San Joaquin Basin Province, California: U.S. Geological Survey Professional Paper 1713, Chapter 12, p. 1-35 [http://pubs.usgs.gov/pp/pp1713/].

Peters, K.E., ed. 2009: Basin and petroleum system modeling: American Association of Petroleum Geologists Getting Started Series No. 16 compact disk, AAPG/Datapages, Tulsa, Oklahoma, http://bookstore.aapg.org/.


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