High Resolution Prediction of Rock Properties and Hydrocarbon Charge through an Integrated Basin Modeling / Seismic Inversion Approach

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Present day rock properties are a result of several physical and chemical processes occurring over millions of years in sedimentary basins. Compaction, clay transition and dehydration, quartz cementation, faulting and fracturing, salt movement and related thermal anomalies, chemical compaction, tectonics, etc., have direct impact on the evolution of rock properties such as porosity, permeability, and thermal conductivity. Basin modeling provides an integration platform where most of the processes are modeled.

Classical seismic inversion deals with present day data and rarely utilizes basin modeling results. In addition to the data derived from wells, fluid and gas distribution, temperature and pressure history derived from basin models can be used for calibration of seismic inversion. This paper presents an approach linking high resolution basin modeling with seismic inversion that led to better predictions of hydrocarbon distribution as well as to better constrained seismic inversion.

Plamuk field (Gulf of Thailand) was selected to demonstrate the workflows. Field selection was based on excellent well control (~200 wells), good quality seismic data, and existing production. Production data shows very complex fluid and gas types: methane, CO2, light oil, heavy oil, and high wax oil. The difficulty in predicting fluid distribution, raise many questions regarding hydrocarbon sources, migration, charge history, re-migration, and mixing. The integrated basin modeling / seismic inversion approach was applied to explain the complex Plamuk petroleum system.

Modeling Pore Pressures and Fluid Flow in a Faulted Shelf System Using a 3D basin Model Coupled to Seismic Velocities

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Basin modeling can provide important insights into fluid flow and pore pressure patterns when input information is of sufficient quality to allow for meaningful results. An example of modeling results from a shelf setting in which the depth of pressure onset is variable and was poorly understood demonstrates how the modeling exercise can clarify which processes are likely producing observed patterns. Pressure evaluation was needed both for prospect assessment and for well planning as pressures approach lithostatic in some offset wells. It was hypothesized that sand distribution, fault juxtaposition and resultant cross-fault flow were the keys to understanding the variability of the onset depth and severity of overpressure in the area. Model results with relatively simple lithology maps based on seismic facies and some special handling of surfaces near faults allowed for a good match to the pattern of well and seismic velocity data. The result of coupling the seismic interval velocity model to the basin model demonstrates the importance of understanding cross-fault flow in this setting, and greatly enhances the value of the simulations. Results also underscore the importance of appropriate model bounds and boundary condition selection.

Quantitative Assessment of Gas Generation and Gas Typing in Petroleum Systems

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The physical properties and generation processes that control natural gas accumulation are distinctly different from those related to oil generation and accumulation and require new tools and strategies in support of effective gas exploration programs. Moreover, natural gas is compositionally very simple compared to the complex chemistry preserved in crude oil, presenting additional challenges for interpreting gas geochemistry. We have developed a new technique that uses the temperature-dependent fractionation of stable carbon isotopes in individual gas compounds which we calibrate with direct closed-system pyrolysis measurements of quantities and isotopic compositions of gases generated from specific source rocks or through secondary cracking of oil. Experimental results can then be extrapolated to any geologic heating rate using new kinetic modeling techniques. With this approach isotope signatures of gas compounds reveal the most critical properties for gas generation and accumulation such as, temperature and maturity of the gas source rock, gas quality (e.g., wetness), and the gas to oil ratio (GOR). Additionally, integration of gas isotope model results with those of basin models allows for prediction of geologically critical information such as timing of gas formation, depth of gas kitchen, amount of gas formed in target areas, etc. Several case studies will be presented to illustrate how gas source-rock isotope calibrations can provide critical information for assessing the type of source, identifying multiply sourced gas, mapping gas migration pathways in the Piceance Basin, characterizing reservoir connectivity, and determining reservoir filling history in the Njord Field in the Norwegian Sea.

A Multi-1D Modeling Approach for Complex Basins; An Example from Taranaki Basin, New Zealand

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Multi-1D, or pseudo-3D, basin models allow basin evolution and expelled petroleum volumes to be rapidly quantified for input to flowpath or full 3D basin flow simulators. The multi-1D BM1D code has been developed from a 1D finite-element conductive heat flow code, and parallelised to permit stochastic modeling with Monte Carlo methods for probabilistic assessment of petroleum prospects. Run times are significantly shortened from single 3D basin simulations by use of a PC-cluster or supercomputer (up to 1000 nodes). While a large number of input maps or grids are required, with isopachs, lithologic composition, depositional ages, and paleo-bathymetric data (all input as grids), the approach provides a detailed basin evolution model accurately accounting for the effects of time-transgressive deposition, volcanic intrusions and erosional unconformities.

New Zealand's Taranaki Basin has a complex history, including rift transform, passive margin, foreland fold-thrust belt,

arc volcanics and back-arc rift elements. The modeling of petroleum systems within such complex polyphase basins therefore requires a specialist modeling code. Regional models are presented from BM1D for the Taranaki Basin illustrating how this diverse input data-set can rapidly characterise basin evolution and quantify volumes of petroleum phases expelled from source rocks through time. The data is available for direct input to map-based flowpath or full 3D fluid flow models for fluid-migration and prospect charge assessment.
This approach provides a sensitivity analysis for input parameters, considerably enhancing prospect risk assessment, and can relatively rapidly produce (pseudo) 3D structural or generation history models for petroleum exploration in complex sedimentary basins.

Two Dimensional Basin Modeling and Petroleum System Critical Analysis of La Concepción Field, Lake Maracaibo, Venezuela

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Two dimensional basin modeling of La Concepción Field, Venezuela reveals the significant impact of pulsed tectonics upon the maturation and migration of hydrocarbons in the prolific Maracaibo basin. Principal source rock criticals include the Type II La Luna Formation (95 Ma) and the Machiques Member (125.7 Ma). Initial oil generation occurred around 60 Ma, expulsion at 45 Ma, and cracked gas around 40 Ma. Principal migration criticals were cross-linking fault zone pathways in the carbonates and through juxtaposed reservoirs in the siliciclastics. Reservoir rock criticals consist of the Cogollo, La Luna, and Guasare fractured limestones and the Eocene Misoa sandstones. Tectonic activities provided four distinct phases of structuring and thermal perturbations and yielded two distinct petroleum systems: the Cretaceous and the Cretaceous/Eocene.
Thermal maturity analysis and migration modeling suggest the timing critical for the Cretaceous petroleum system first opened in the Mid-Eocene (43 Ma). The structural trap forming processes commenced in the Late Cretaceous and were completed by the Mid-Paleocene. Substantial generation, migration, accumulation and preservation of hydrocarbons immediately ensued. Lying in a tectonically dynamic region, La Concepción Field underwent a multi-staged deformation resulting in the formation of both structural and stratigraphic traps. Structural traps include faulted blocks, anticlinal features, and transpressional flower structures. Stratigraphic traps are sandstone lenses and pinch-outs within the Misoa Formation shale units. The extensive amounts of small-scaled faults and reactivated basement-involved, high-angle faults suggest that rheologically, La Concepción Field represents present-day transpressional elastic deformation providing dominantly vertical hydrocarbon migration.