MIDLAND BASIN

HYDROCARBON PHASE STUDY

KINETIC GENERATION MODELS AND EXPLORATION/PRODUCTION SIGNIFICANCE FOR THE SPRABERRY, WOLFCAMP, AND CLINE FORMATIONS OF THE MIDLAND BASIN

A PROPOSAL OFFERED BY

GEOMARK

and

GEOS 4

MIDLAND BASIN HYDROCARBON PHASE STUDY

EXECUTIVE SUMMARY

We are pleased to announce the initiation of a petroleum geochemical study designed specifically to **improve predictions of hydrocarbon yield and phase properties**. This study incorporates multi-component kinetic measurements combined with compositional analyses to provide tools for predicting bulk properties and yield estimates before drilling and/or leasing. This study draws on GeoMark's past studies in the region and utilizes GeoMark's proprietary Rock & Fluid Database (RFDbase, Figure 1) to select source rock samples for the analytical scheme described in the Methodology section of this proposal. GeoMark is working with the company Geos4, using their proprietary analytical and interpretive programs to accomplish this study. The objectives/deliverables are listed below.

- Construct maps showing sourced rock character, quality, and thermal maturity of all studied formations.
- Build empirically derived facies models for all source rock units documenting vertical and horizontal variations in character of organic facies.
- Determine the extent of hydrocarbon migration by formation and geographic location.
- Develop graphs, and maps documenting cumulative oil and gas generation, retention, and migration.
- Map predicted fluid properties (e.g. GOR, density/gravity, etc.) for each formation, defining the "hard" limits to the "sweet spot" fairways.
- Provide yield estimates by formation and basin location.
- Map zones of increasing/decreasing economic potential based on yield estimates.
- Construct a PhaseKinetic Database in the Midland Basin that can be used in other analogous plays.

Participating companies will receive analytical data from all analyses, defined later in this proposal, as well as a full interpretive report.

The cost of this project is $75,000. We will start the project when four companies have committed to the program. The project will require approximately 8 months to complete.

INTRODUCTION

Recent work by GeoMark, GEOS4 and others, has shown that using standard kinetic models in unconventional plays is insufficient for predicting the reservoir fluid properties of generated hydrocarbons. Applying simplistic input parameters such as "Type II marine kerogen", cannot adequately model the complex fluid properties seen in most unconventional resource plays. This is particularly true in the Permian section of the Midland Basin because of the large facies variability (both vertically and laterally) of the Spraberry, Wolfcamp, and Cline Formations. Exploration companies need better tools for predicting fluid properties (GOR, bulk petroleum phase volumes, etc.) to define the economic "sweet spot" and enhance resource exploitation efforts.

GeoMark and GEOS4 believe that an accurate measurement of kinetic generation attributes combined with detailed compositional analyses can be used to develop the tools needed for the successful estimation of fluid properties and a better prediction of yield volumes. **With this information participating companies will be able to make accurate yield and composition estimates, leading to better economic forecasting prior to drilling and perhaps leasing.**

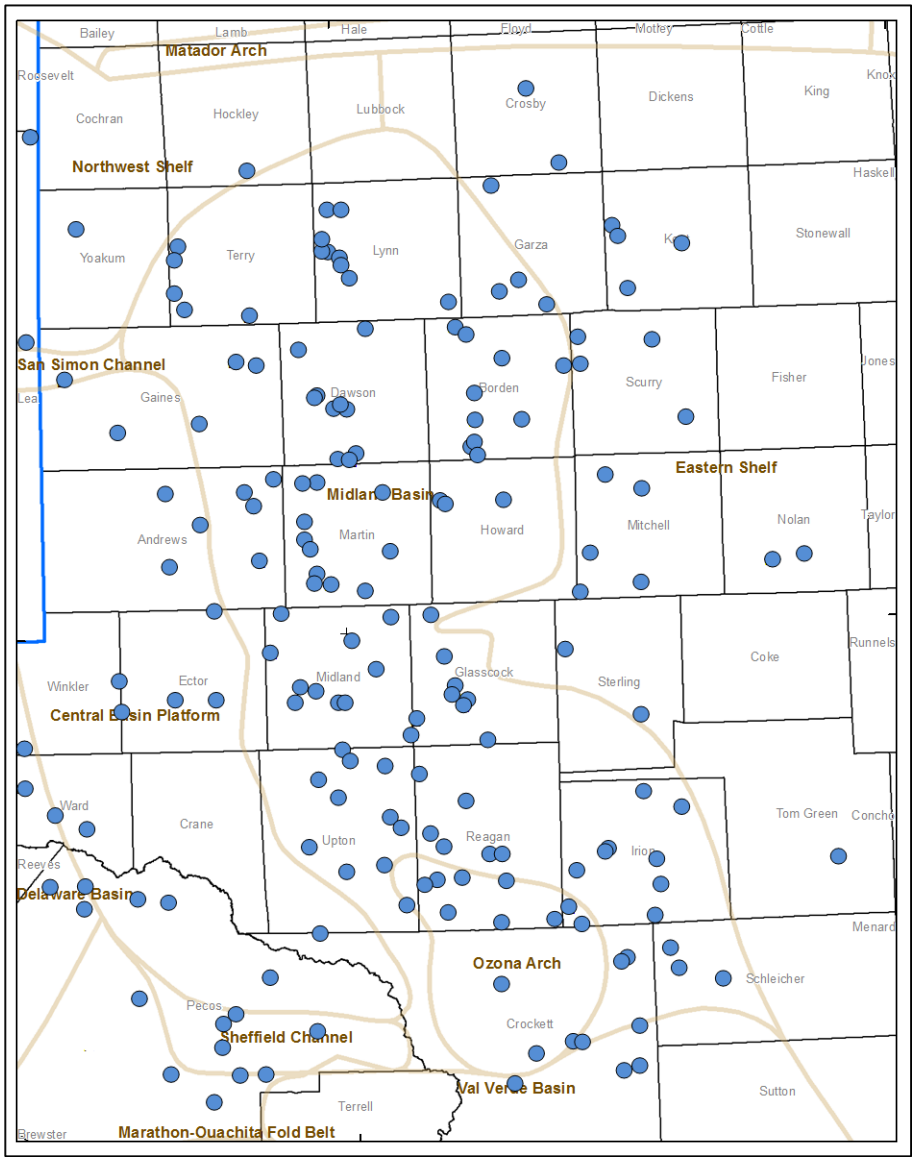

Figure 1 - Wells with Spraberry, Wolfcamp, and Cline source rock data from GeoMark's RFDbase Database.

TRACK RECORD OF THE APPROACH

The ultimate test for any predictive model is whether it can be shown to be validated by natural data. Examples from the Norwegian North Sea, Brazil and Mexico have demonstrated the close correspondence of the tuned compositional predictions with field data (di Primio and Horsfield, 2006). In high pressure, high temperature (HPHT) reservoirs of the North Sea, which can be considered closed systems, black to light oil GOR distributions in the North Sea Viking Graben closely matched the predictions of MSSV (MicroScale Sealed Vessel) pyrolysis experiments performed on the Draupne Formation source rock (di Primio and Skeie, 2004; cf. Vandenbroucke et al., 1999). di Primio and Neumann (2008), in a similar study of the Jade and Judy Fields in the Central Graben of the North Sea that included pressure prediction, reported that GOR predictions from MSSV pyrolysis bore a close

resemblance to the natural HPHT system. Other examples of excellent GOR predictive capability are provided by modelling of the Egret Shale and its generated petroleum in the Jeanne d'Arc Basin, Canada (Baur et al., 2010), and the Bakken Shale and its generated petroleum in the Williston Basin, USA (Kuhn et al., 2010, 2012). The PhaseKinetics (compositional kinetic modelling) evaluation of unconventional plays in the UK (Yang et al., 2015), China and Australia (Tan et al., 2013) have been published.

As an example, Figure 2 shows PVT phase behavior envelopes generated via the PhaseKinetics approach. Having this type of information for each formation calculated for various locations throughout the Midland Basin will greatly assist companies with exploration and exploitation decisions.

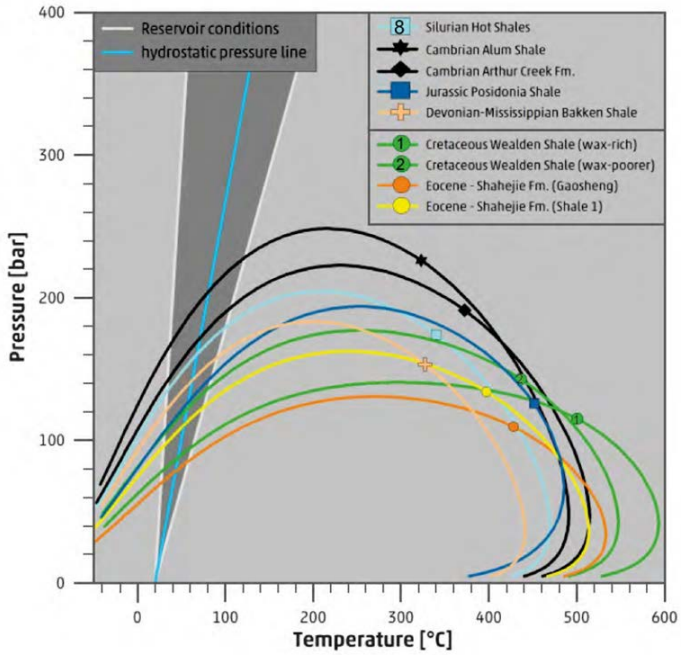

Figure 2 – MSSV-pyrolysis petroleum compositions converted to phase envelopes from several different source rocks.

MIDLAND BASIN PERSPECTIVE

In the Midland Basin we know that petroleum yields and bulk compositions vary widely (both vertically and laterally) because of inherent organofacies differences (richness, quality, thermal stability) and the superimposed effects of maturity and hydrocarbon retention capacity. There is also a real risk that phase separation of gas and oil can occur through a lack of confining pressure during production from shale reservoirs, thereby resulting in sudden changes in relative permeability and associated drops in production rate. Also, phase separation can occur during fluid migration.

The way to solve this problem is to use MSSV pyrolysis and PVT simulation software (PVTsim) to predict in-place bulk generation characteristics and then compare with GOR and PVT data from engineering reports. In addition, comparing oil geochemical maturity estimations from biomarkers compared to local source rock maturity will help determine the extent of migration.

DATA SOURCES

GeoMark's RFDbase (and associated Midland Basin sample set) will be used to select the source rock samples to be submitted for the various kinetic measurements. The Database currently holds over 4,000 Spraberry, Wolfcamp, and Cline source rock measurements, ensuring appropriate choices for subsequent geochemical measurements. Also, RFDbase contains crude oil analyses to help constrain the source rock type and maturity estimations, and aid in predicting the extent of migration.

ANALYTICAL PROGRAM

The work program is built around PhaseKinetics modeling. This is a compositional kinetic modelling approach that is based on (1) pyrolysis gas chromatography to establish petroleum type organofacies, (2) bulk flow pyrolysis to determine bulk petroleum generation parameters, (3) MSSV pyrolysis to determine bulk compositions at selected transformation ratios, and (4) tuning to configure results in a PVT-amenable format. Analytical details are given in the Appendix.

As a first step, we will compile Rock-Eval data pairs for original and solvent-extracted samples (100 pairs) in order to build a facies and maturity grid across the study area for the three target formations. Source richness, quality and maturity will be evaluated.

Pyrolysis gas chromatography (60 samples) will then be employed to recognise differences in kerogen structure that ultimately control the starting GOR and fluid composition across the study area.

Bulk kinetic parameters of petroleum generation (20 samples) will be determined enabling generation in time-temperature space to be modeled with due consideration of both facies and maturity.

The activation energy distributions of selected samples (10) will be populated with molar abundances of individual gases (C_1-C_5) and boiling ranges (C_{6+}) gathered at five levels of transformation using MSSV pyrolysis; tuning will be used to configure results in a PVT-amenable format. PVTsim software will then be applied for predicting *in-situ* GOR and Psat (bubble/dew point). Both cumulative and instantaneous charges will be considered.

Mass balance modeling, utilizing Rock-Eval, pyrolysis gas chromatography and thermovaporisation will be used to determine levels of expulsion or enrichment; bulk fractions and selected compound classes in the three studied formations will be examined.

INTERPRETIVE REPORT

Results will be presented at regional scale to facilitate trend recognition. Selected areas will be examined with enhanced resolution and reference to PVT reports.

Regional Synthesis

We will assess source richness, OM type and maturity of the Spraberry, Wolfcamp and Cline using parameters based on Rock-Eval data. We will then use kerogen structural attributes (chain length distributions, sulfur and phenols) to monitor the changing of petroleum type and

intrinsic GOR as a function of facies and maturity. We will provide maps and tables to contrast evolving characteristics.

Kinetic parameters associated with all generation levels up to and including the highest sampled maturities will be presented, and predictions linked to thermal history using basin modeling software. Cumulative and instantaneous yields will be calculated, and a calibration afforded by regional trends in HI. We shall assess fluid migration and retention efficiency using mass balancing based on several methods, namely volatile oil, total oil (Delvaux et al., 1990) and individual hydrocarbons (Santamaria and Horsfield, 2003), thereby enabling retention/expulsion efficiency to be calculated. The results from the PhaseKinetics approach utilizing immature samples, namely cumulative and instantaneous GOR and Psat, will be presented and compared with measured data,

Additional Focus on Selected Areas

Snapshots of phase behavior will be presented for the Spraberry, Wolfcamp and Cline at high resolution by considering instantaneous generation products *in mature wells*. We shall utilize PhaseKinetics and PVTsim to predict in-place generation characteristics, and compare the results with GOR and PVT data from engineering reports.

DELIVERABLES

All analytical data from the Midland Basin Hydrocarbon Phase Study will be provided digitally. Interpretive commentary will be provided in an Adobe PDF document. Microsoft Excel™, Access™, and ESRI ArcGIS™ raster and feature data will be the data formats and mapping system used by GeoMark in this project. This will allow easy import of shapefiles to PETRA™ or GeoGraphix™ software packages.

FINAL INTERPRETIVE REPORT

A final interpretive report will be issued for this project.

PARTICIPATION AND TIMING

The cost of this project is $75,000. We will start the project when four companies have committed to the program. The project will require approximately 8 months to complete.

For additional information, please contact:

GEOMARK RESEARCH, INC.
9748 Whithorn Drive
Houston, Texas 77095
Telephone: (281) 856-9333
Fax: (281) 856-2987
info@geomarkresearch.com

GEOS4 GmbH
Peter-Huchel-Chaussee 88
14552 Michendorf, Germany
Telephone: +49 (0)331 288 17 80
Fax: +49 (0)331 288 17 82
info@geos4.com

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APPENDIX A – STEP-BY-STEP METHODOLOGY

Source Rock Evaluation – Since 2009 GeoMark has performed Total Organic Carbon and Rock Eval pyrolysis analyses on over 4000 Permian samples from the Midland Basin. These data are being evaluated to select 100 samples for the detailed kinetic and compositional analyses described below.

In-place pay projection
- Volatile oil
- Total oil
- Heaviness Index
- Oil quality

Source characteristics
- Kerogen type and maturity
- Residual generative potential
- Kerogen versus bitumen

Retention capacity
- Crossover
- Link to labile carbon

Regional Oil Study – In the Permian Basin of West Texas and Southeastern New Mexico GeoMark has analyzed over 1,000 crude oil samples and classified them by age and thermal maturity. These data will be used to determine where migration has occurred and estimate the extent (distance both vertically and horizontally). This will be critical when determining if the evaluated facies unit is a closed system from a generation and migration standpoint.

Thermal maturity differences between oil and reservoir rock
- Closed vs. open system
- Fractionation of migrating hydrocarbon
- Distance of Migration

Thermovaporization – this method will be employed to analyze free hydrocarbons in 60 selected unheated samples, and performed using the Quantum MSSV-2 Thermal Analysis System®.

Milligram quantities of each sample are sealed in a glass capillary and heated to 300°C in the injector unit for 5 minutes. The tube is then cracked open using a piston device coupled with the injector, and the released volatile hydrocarbons are focused using a liquid N_2 cryogenic trap, and then analyzed using a 50 m x 0.32 mm BP-1 capillary column (film thickness 0.52 μm) equipped with a flame ionization detector. The GC oven temperature is programmed to increase from 40°C to 320°C at 8°C/minute. Major resolved peaks are quantified.

Retention capacity
- Individual hydrocarbon yields are used in the compositional mass balance model

Pyrolysis Gas Chromatography – Pyrolysis gas chromatography will be performed on 60 selected samples using the Quantum MSSV-2 Thermal Analysis System®.

Thermally extracted (300°C, 10 minutes) whole rock samples are heated in a flow of helium, and products released over the temperature range 300-600°C (40°/min) are trapped then analyzed as described above for thermovaporization. Boiling ranges (C_1, C_2-C_5, C_6-C_{14}, C_{15+})

and individual compounds (*n*-alkenes, *n*-alkanes, alkylaromatic hydrocarbons and alkylthiophenes) are quantified by external standardization using *n*-butane.

Lateral and stratigraphic source signatures

- Organofacies based on source chain length and sulfur species
- Link between production type and kerogen structure building blocks

Generated charge

- Individual generated hydrocarbons are utilized in the compositional mass balance model

Bulk Kinetics Determination – Twenty (20) samples will be analyzed by non-isothermal open system pyrolysis at four different laboratory heating rates (0.7, 2.0, 5.0 and 15°/min) using a HAWK® pyrolysis unit. The generated bulk petroleum formation curves serve as input for the bulk kinetic model.

The mathematical model assumes 40 first-order bulk petroleum generation reactions with activation energies regularly spaced between 46 and 85 kcal/mol and a single frequency factor. A total number of 41 parameters are optimized by a least squares iteration that compares measured and calculated rates until the corresponding error function (sum of squared differences) presents a well-defined absolute minimum. The assumption of first-order kinetics for each parallel reaction is in general accordance with experimental findings and theoretical considerations concerning the sequences of radical reactions involved in petroleum generation.

Bulk kinetic parameters for direct import into petroleum system models

- Activation energies and a frequency factor
- Generation intensity and breadth in time-temperature space

Compositional Kinetics Determination – MSSV pyrolysis, or Microscale Sealed Vessel pyrolysis (Horsfield et al., 1989), will be used to gather the compositional data for populating the PhaseKinetics model (di Primio and Horsfield, 2006). Ten (10) samples will be analyzed using the Quantum MSSV-2 Thermal Analysis System®.

Milligram quantities of each sample are sealed in glass capillaries and artificially matured at 0.7°/min using a special MSSV prep-oven to five levels of thermal transformation (TR = 10, 30, 50, 70, 90%). The tubes are then cracked open using a piston device coupled with the injector, and the released products trapped are then analyzed as described above. Individual compounds in the gas range (C1-C5), coarse boiling ranges (C_1, C_2-C_5, C_6-C_{14}, C_{15+}) and 25 pseudo-boiling ranges for each carbon number at and above C_6 are quantified, the format being compatible with PVT reporting protocols. Tuning of gas compositions takes into account fundamental differences in wet–to-dry gas ratios between natural and laboratory pyrolysis heating rates.

Compositional kinetic parameters for direct import into petroleum system models

- 14 compound, phase predictive kinetic model
- 2-compound and 4-compound models are also provided
- Compositional evolution – cumulative and instantaneous charges
- Geofiles prepared for direct import into modeling software