# Source Rock Kinetics – An Often Neglected Variable in Petroleum System Analysis*

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## Abstract

In basin modeling, a great amount of time and effort is invested to reconstruct the evolution of a wider basin area as well as the lithological composition and physical characteristics of the deposited sediments to predict temperatures and pressures in the subsurface. To model the generation of hydrocarbons from the kerogen "standard" kinetic datasets, which are thought to be representative of the source rock found in the basin, are applied. These kinetics usually stem from published datasets or are those provided with the basin modeling software. However, they may not only be misrepresentative of the actual source rock but they will most likely also neglect the potential variability of the kerogen in terms of its thermal stability and transformation behavior. Incorporating standard source rock kinetics might be a good first approach to identify main kitchen areas and to set up an initial model in the absence of individually measured kinetics. However, a full assessment whether the inaccuracy related to standard kinetics devaluates the effort related to the extensive data gathering and refinement to build and calibrate the model needs to be performed.

## Introduction

When modeling the resources in-place in a conventional setting a change of the generated volume might not have such a high impact. This mainly relates to migration as one of the least constrained parameters, which is therefore a difficult process to predict in the subsurface. On the other hand, for unconventional settings with a less pronounced impact of the ambiguities linked to migration and with production locations more closely related to the areas of hydrocarbons generation, a better knowledge on the volume of the latter is necessary. Important as it is for a gas play, the significance of the correct understanding of the kerogen transformation even increases when dealing with a low permeability oil play. Not only has the onset of the generation of the resources to be modeled correctly for these plays but also the composition of the generated products at the different transformation stages and the potential destruction due to secondary cracking.

For example during the construction of a Williston Basin – Bakken Formation petroleum system (Kuhn et al., submitted) a model with a low permeability (< 10-6 D) settings was designed. To account for the source rock characteristics of the Bakken, a custom compositional kinetic dataset was defined based on bulk kinetic measurements and populated with compositional information derived from closed system artificial maturation experiments (MSSV pyrolysis - Horsfield, 1989). All analyses were conducted on low mature source rock samples. The fact that measurements on individual samples are only representative of the small amount of source rock material analyzed and cannot assess potential inhomogeneities or lateral variability (Keym et al., 2006) is an issue that needs to be addressed. For the Bakken the transformation behavior of 12 samples was tested and the monitored variability was compared to the error ranges of other input variables of the basin model (e.g. original TOC, maximum amount of inversion/erosion, residence time at deepest location).

## Discussion

A simple approach to address kinetic variability is to determine and compare transformation ratio evolution at a constant geologic heating rate for all samples. Using a heating rate of 3°C per million years the temperature difference in the tested samples at 50 % transformation of the source rock generation potential has a range of 13°C. For a gradient of 30°C/km, this variability can be translated into an error of ± 216m of the maximum burial depth.

Alternatively, sensitivity studies can be performed using basin model scenarios. This allows testing of different input variables and their significance for the output, e.g. shifting the activation energy of the source rock kinetics by ±1kcal/mol. This change decreases/increases the volume of hydrocarbons in the context of the Bakken Formation in the Williston by approximately 30% (Table 1) and is reflected by a transformation ratio variability of up to ±8°C for geologic heating rates. In consequence, this shift of the activation energy has a higher impact on the volumetric output than the variability found in the analyzed source rock samples. This has to be added to the inaccuracy related to the burial and temperature history of the model. For the Bakken Formation in the 3D model these results imply that sensitivity with respect to the natural kinetic variability of the source rock is minimal and the use of standard kinetic models in this exercise would lead to a much higher error margin.

Using commercially available and proprietary basin modeling software packages, we tested the potential impact of standard kinetics and compared them to the output of specially adapted source rock kinetics on simple generic models. In projects with low data coverage, this should allow a first pass benchmark test if a standard kinetic is adequate or if custom designed kinetics should be considered.

## Conclusions

In future basin modeling projects, especially where the amount of generated hydrocarbons is a key variable determining the feasibility of a petroleum play, it is advised to include the variability of the source rock kinetics into a sensitivity analysis. This could especially play a role in low permeable petroleum plays where the stability of the original kerogen and the generated products has to be considered. If the applied kinetics are the least constrained input parameter, one is advised to consider more detailed analysis of the source rock transformation behavior and delineate errors related to these custom kinetics.

If more detailed analysis of the in-situ source rock is not available, it is advised to include an error on the standard kinetic in a sensitivity testing.

Presenting this concept, we would like to highlight:

- Standard kinetic should always include their error range.
- How can the error related to the kinetics be compared to other input parameters?
- What error related to the used kinetic is acceptable in basin modeling?
- What can we do to prevent a potentially greater error related to the used of standard kinetics?
- Special attention has to be paid to low permeability settings where the resources in place are strongly related to the hydrocarbons generated.

## References Cited

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| Variable | Tested range | Applicable variability range | Negative impact variable | Reference model | Positive impact variable |
|---|---|---|---|---|---|
| **Volume of org. TOC** | Reference TOC map X 0.5 & 1.5 | well constrained - no greater range applied | TOC X 0.5 | - 51 % + 50 %<br>- 50 % + 50 % | TOC X 1.5 |
| **Maximum burial depth / erosion** | max. inversion at basin centre 365 - 1090 m | 550-700 ±200 m | - 200 m | - 22 % + 18 %<br>- 22 % + 13 % | + 200 m |
| **Residence time at deepest location** | 0.1 - 6 Ma | 0.1 - 3 Ma | 3 Ma | + 2.0 % + 23 %<br>+ 3.0 % + 23 % | 6 Ma |
| **Kinetic - max. activation energy** | 52 - 57 kcal/mol | 56 ±1 kcal/mol | + 1 kcal/mol | - 29 % + 31 %<br>- 28 % + 25 % | - 1 kcal/mol |
| **Heat flow - maximum** | 74 ± 5 $mW/m^2$ | 74 ± 1 $mW/m^2$ | - 1 $mW/m^2$ | - 8.2 % + 7.9 %<br>- 10 % + 4.5 % | + 1 $mW/m^2$ |
| **Permeability** | permeability ± $10^3$mD | reference permeability X $10^{\pm 0.5}$ mD | $10^{+0.5}$ mD | no impact on generation<br>- 7.1 % + 0.2 % | $10^{-0.5}$ mD |

hydrocarbons generated / retained in the Bakken Formation

Table 1. Comparison of different input variables and their effect on the modeled petroleum volumes. Based on the context of the constructed model, the ranges of variables tested and the variability ranges that could potentially play a role are listed. The tornado plot shows the impact of the ranges of the variables applicable in the context of the tested basin model (except for original TOC) and the respective impact on the generated and retained hydrocarbons in place (after Kuhn et al., submitted).