Rock-Eval Pyrolysis Data Analysis and Kerogen Kinetics Comparison of Selected Producing and Potential Shale Gas Plays in Canadian Sedimentary Basins*

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Search and Discovery Article #80557 (2016)**
Posted October 31, 2016

*Adapted from oral presentation given at AAPG 2016 Annual Convention and Exhibition, Calgary, Alberta, Canada, June 19-22, 2016

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Abstract

Petroleum resource development from shale reservoirs is capital intensive. A quick and reliable evaluation of shale resource play and early identification of "sweet spots" are critical to competitive advantages. Since organic-rich shales are both source rock and reservoir, generation capacity, kerogen kinetics, and maturity are the essential elements in play evaluation. Rock-Eval pyrolysis has been widely accepted by the industry as a useful tool as the analytical results can provide a quick, easy and cost effective way for source rock evaluation. However, there are misconception and confusion in applying the Rock-Eval data to source rock evaluation due to difference in the maturity status of individual samples, and the embedded maturity variation could lead to unsatisfactory results if mishandled in data interpretation. Appropriate interpretation from a perspective of hydrocarbon generation kinetics may shed light for a better understanding of thermal maturation and generation capacity of the source rock under examination. This study examines Rock-Eval pyrolysis datasets from 23 source rock systems of selected producing and potential shale gas plays in Canada through application of newly developed methods or tools for source rock evaluation. Kerogen kinetics was examined using a data-driven model designed for geologists and entirely based on Rock-Eval data. The hydrocarbon generation potentials are determined via restoration of initial hydrogen index and TOC. This study also proposes the use of a dimensionless plot of S2 versus TOC to remove the effect of different maturities on determining type of kerogens in data interpretation. A comparison of organic rich shales in Canadian sedimentary basins under this study reveals large variation in hydrocarbon generation capacity and kerogen kinetics even for the same types of kerogen. A comparison of the source rock kinetics of major producing shale gas plays in Canada with those from the United States shows similarities and differences in kerogen compositional features of the hosting shale reservoirs. This presentation discusses various methods, presents the results and demonstrates the innovative approaches of studying oil generation kinetics and resource potentials using conventional Rock-Eval data without involving specially designed and costly laboratory pyrolysis experiments.

References Cited

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Chen, Z., and C. Jiang, 2015, A Data Driven Model for Studying Kerogen Kinetics with Unconventional Shale Application: Examples from Canadian Sedimentary Basins: Marine and Petroleum Geology, v. 67, p. 795-803. doi:10.1016/j.marpetgeo.2015.07.004

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Outlines

- Introduction
- Dimensionless TOC-S2 plot
  - Method
  - Application examples
- Comparison of SR transformational characteristics for selected source rocks
  - Methods for comparison
  - Examples
- Summary

Introduction

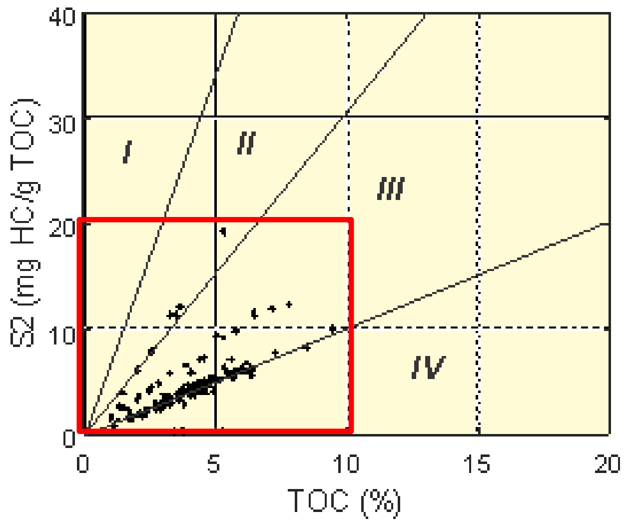
- Resource play:

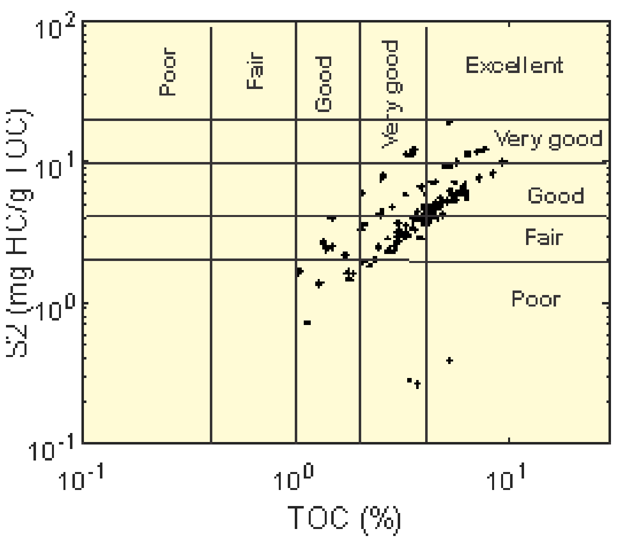
  source rock = reservoir = trap = top seal

  Source rock evaluation becomes the most important part in a resource play evaluation

- Richness and thermal maturity of SR are fundamental to ensure meaningful resource potential in a play
- ***kerogen type and kinetics*** are important factors affecting HC fluids, which are crucial in prediction of dynamic sweet spots

A traditional TOC-S2 plot





- A useful tool for interpretation of kerogen type
- But based on the assumption that samples are at similar thermal maturity
- May lead to improper conclusion if the assumption violated

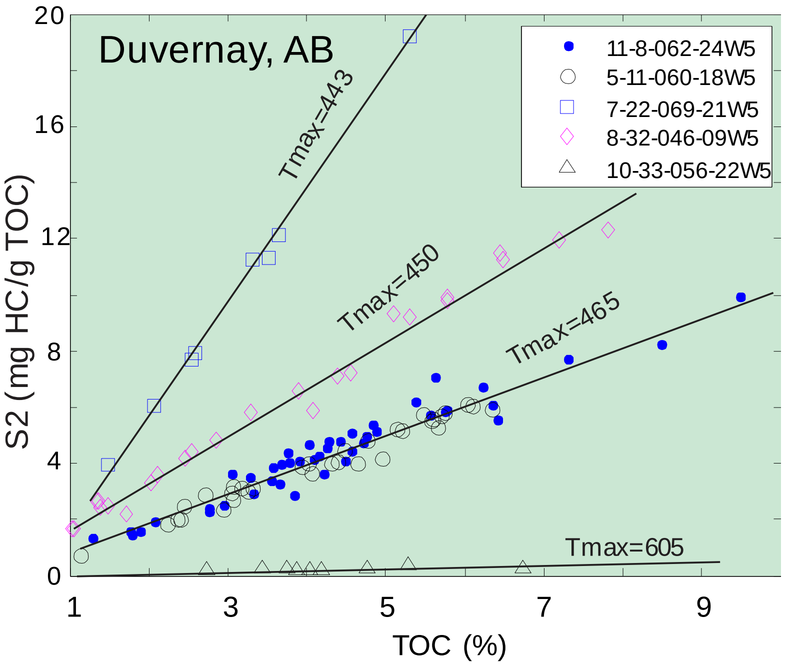
- Devonian Duvernay Shale Example
  - Samples from five recent Duvernay wells
  - From the same SR with similar generation kinetics
  - Very different burial depths and thermal maturities
- Traditional TOC-S2 plot suggests a mixture of different kerogens, mostly type III although abundances of TOC & S2 suggest fair to excellent source rock

Maturity effect on TOC-S2 plot

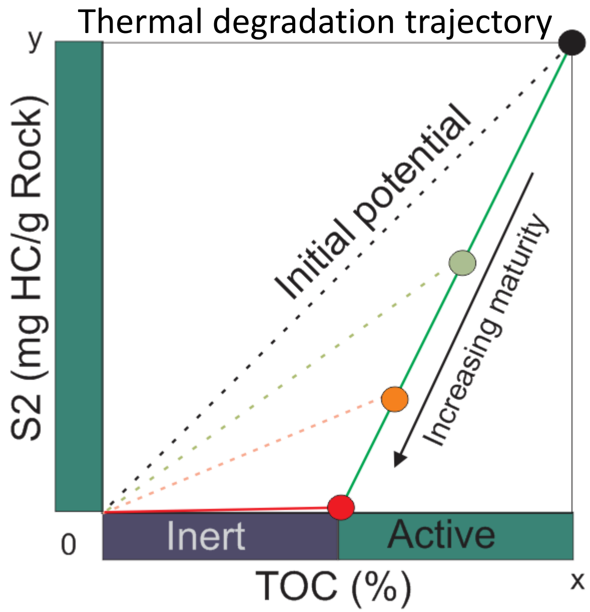
Same dataset, sorted by wells

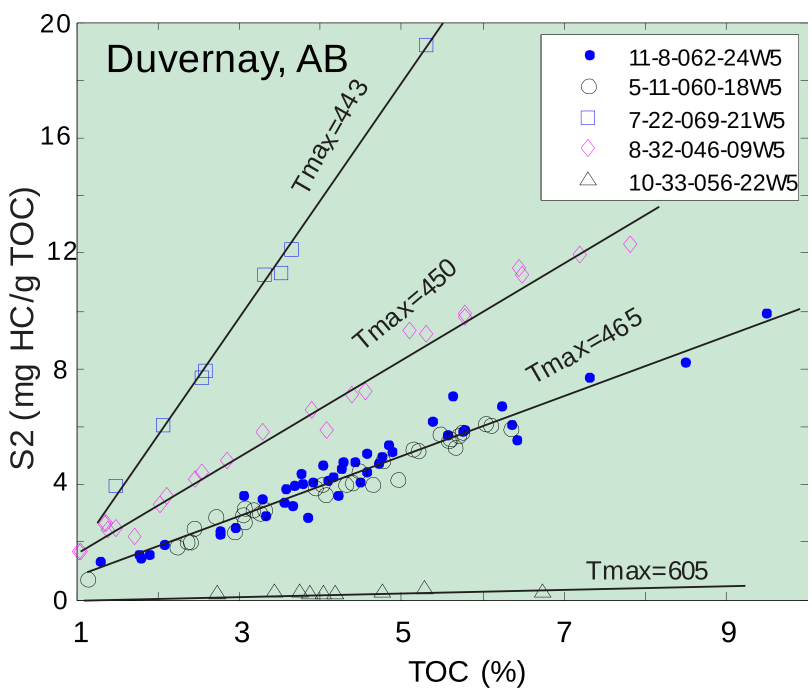
Observations:

- Samples in the same well fall in a single line
- Slope decreases with increasing thermal maturity;
- Over-mature samples show no generation potential with lowest slope and variable TOC contents



Maturity Effect on TOC-S2 plot





Thermal degradation trajectory

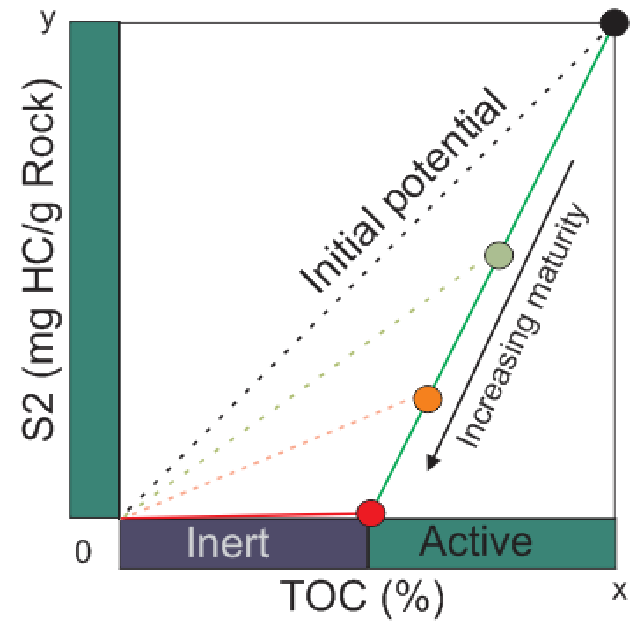
- TOC consists of inert organic carbon and active organic carbon;
- Only active carbon is convertible to hydrocarbon
- Samples with same generation potential and maturity fall in a line
- S2 is strictly proportional to active TOC. Higher maturity remove part of active TOC and S2 accordingly, forming a new line
- Remaining generation potential decreases with increasing maturity, so does the slope

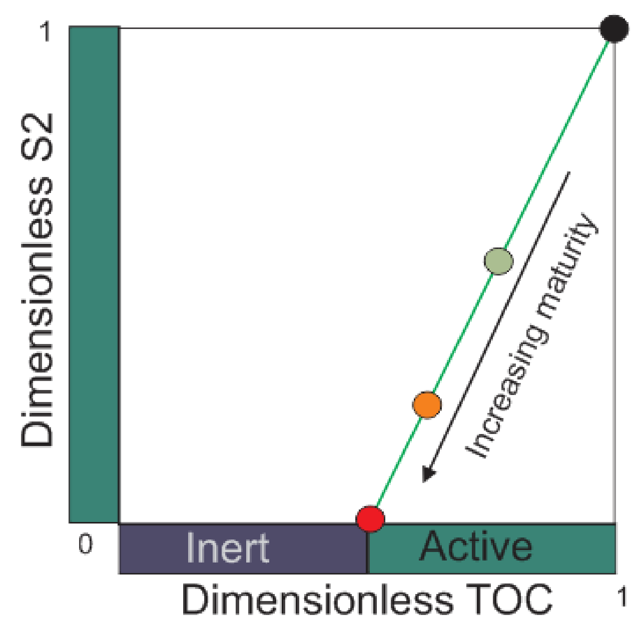
Duvernay example

- ~50 m thickness, so samples from each well have approximately the same maturity
- Data along a line indicate similar remaining generation potential (HI=S2/TOCx100: HC mg/g TOC)
- Variation in each line represents difference in abundance of organic carbon content
- Remaining generation potential decreases with increasing maturity as indicated by decreasing slopes

Dimensionless TOC-S2 plot

- Divided by their initial values, S2 and TOC become dimensionless with unitary length;
- Scattered data points in a single line converged towards a single point; Location of the data on the new plot is function of maturity and OM quality
- Sample maturation is measured by the distance from initial place [1,1];
- Quality of OM is measured by % of active TOC indicated by the intercept at the Hz axis





(Chen et al., 2016)

A dimensionless TOC-S2 plot

- Dimensionless TOC reaches a minimum @ % of inert TOC when active TOC is depleted
- Dimensionless S2 has a value between 0 and 1. It reaches 0 when all productive TOC is converted to HC

$$TOC_{DL} = \frac{TOC}{TOC_o} = \frac{TOC_A}{TOC_o} + \frac{TOC_I}{TOC_o}$$

$$S2_{DL} = \frac{S2}{S2_o}$$

$$TOC_O = \frac{TOC}{1-\alpha(TR)}$$

$S2_o = HI_O x TOC_O/100$

$$T_R = \frac{1200}{(1200-H_I)} \frac{(H_I^O - H_I)}{H_I^O}$$

(Espitalié et al., 1987)

H_I^O: initial hydrogen index

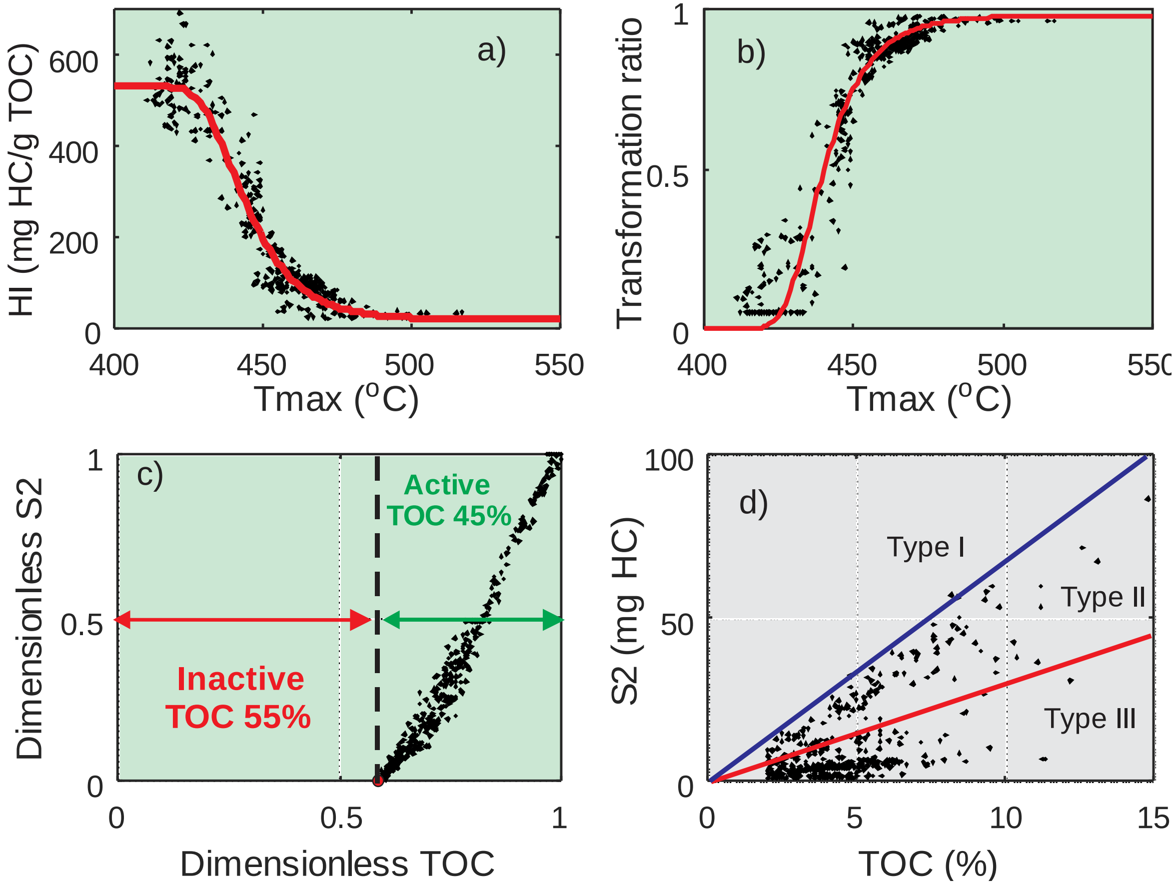
T_R: transformation ratio

Example dimensionless TOC-S2 plot Duvernay Shale, WCSB

A large dataset

Preparation of the plot

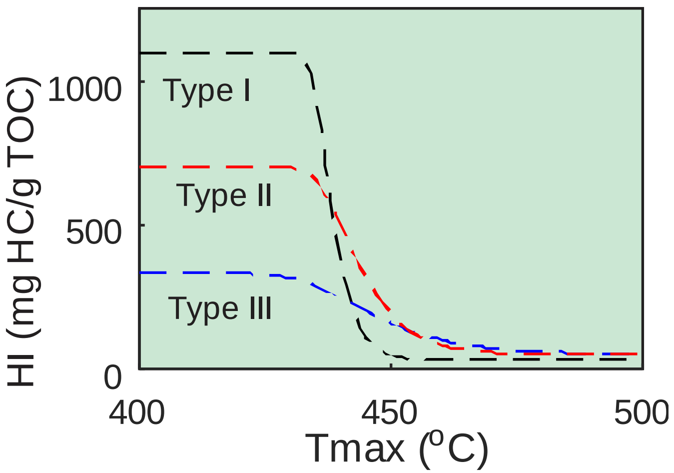
- A fitted SR thermal degradation path (a)
- HC transformation ratio (b)
- Dimensionless TOC-S2 plot (c)
- Comparison to traditional TOC-S2 plot (d)

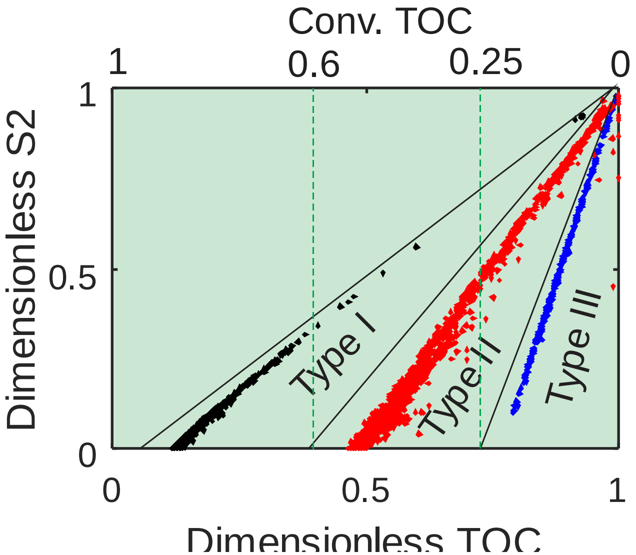


Comparison of different kerogen types

Dimensionless TOC-S2 plot:

- **Black**: Type I kerogen of Eocene lacustrine source rock in Biyang Basin (Chen et al., 2015);
- **Red**: A typical normal marine source rock in WCSB; and
- **Blue**: Type III kerogen of Eocene Enping Fm. lacustrine source rock in the south China Sea Basin (Chen et al., 2015).





Outlines

- Motivation and objectives
- Dimensionless S2-TOC plot
  - Method
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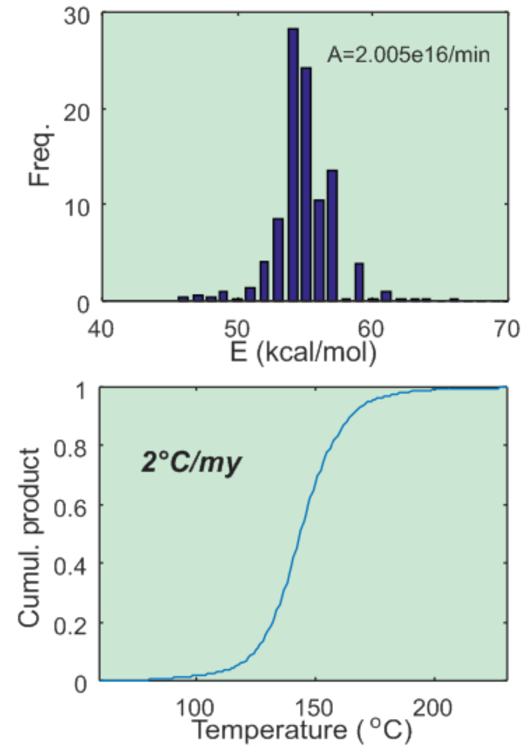
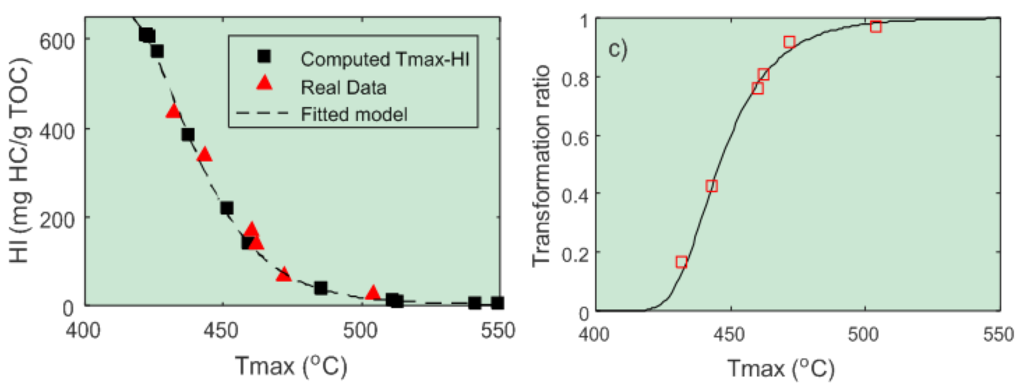
HC generation history modeling vs HC resource evaluation

- Hydrocarbon generation histories in basin modeling (petroleum system analysis)
  - Restores HC generation histories in *geological time (indexed by paleo-temperature)*
  - *Major uncertainty: environmental impacts such as variable heating rates, pressure, geochemistry of formation water and minerals on generation rate*



- Hydrocarbon generation models in quantitative resource assessment
  - *Quantifies hydrocarbon transformation status in present time (indexed by Tmax or other indicators)*
  - *No environmental correction is needed*



Method: a data driven statistic model

A two-step approach

- Fitting HI against Tmax to a statistic model
- Converting the model to TR

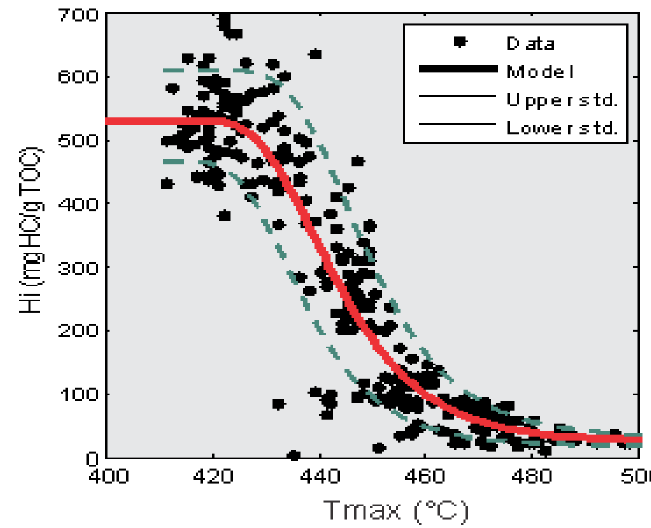
Statistical model has the following form

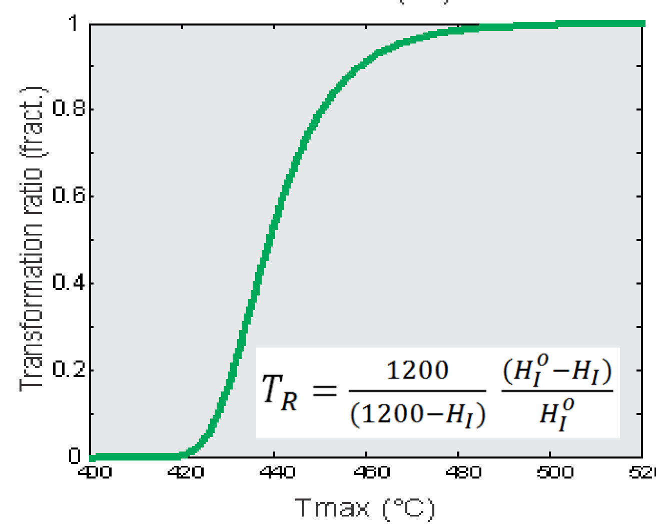
$$H_I = H_I^o \left[1 - \exp\left\{ - \left(\frac{T_{max}}{\beta} \right)^{\theta} \right\} \right] + c$$

H_I^o: initial hydrogen index; β and θ: unknown kerogen kinetics specific parameters; *C*: an error term

- *Initial HI (not HI) is an indicator of kerogen type and generation potential*
- β (°C): pyrolysis temperature at beginning of significant HC generation
- θ: shape parameter of heterogeneity in kerogen kinetics

(Chen and Jiang, 2015 and 2016)



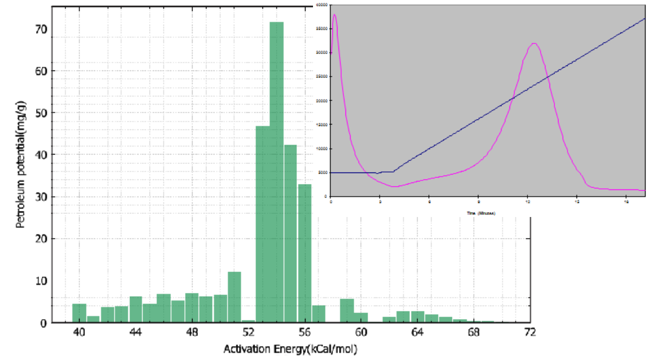


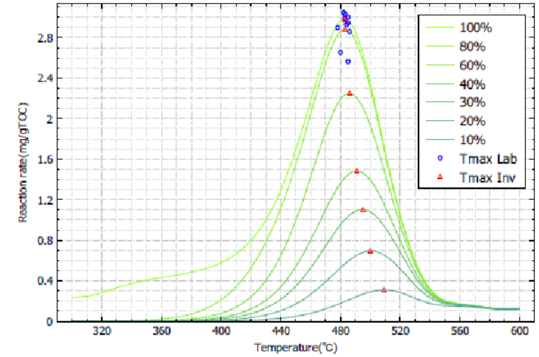
(Espitalié et al., 1987)

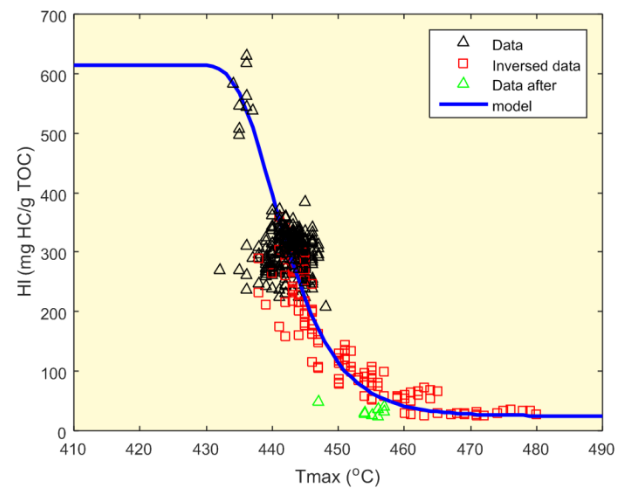
Extract more information from Rock-Eval Pyrograms

When data coverage is poor, Rock-Eval FID-pyrograms can be useful for inferring kerogen transformation behavior at higher temperature

- Data wells are in shallow depths (<2500 m) in Anticosti Basin. Samples at low to moderate maturation, so difficult to define the conversion path at higher maturity level
- Hydrocarbon pyrograms were used to constrain kerogen thermal degradation behavior
  - Estimate the kinetics parameters from pyrograms of SR samples
  - Compute production rate (S2 curve) at different temperatures using the estimated kinetics
  - Generate HI and Tmax pairs
  - The computed HI and Tmax data points are used to constrain the thermal decomposition model



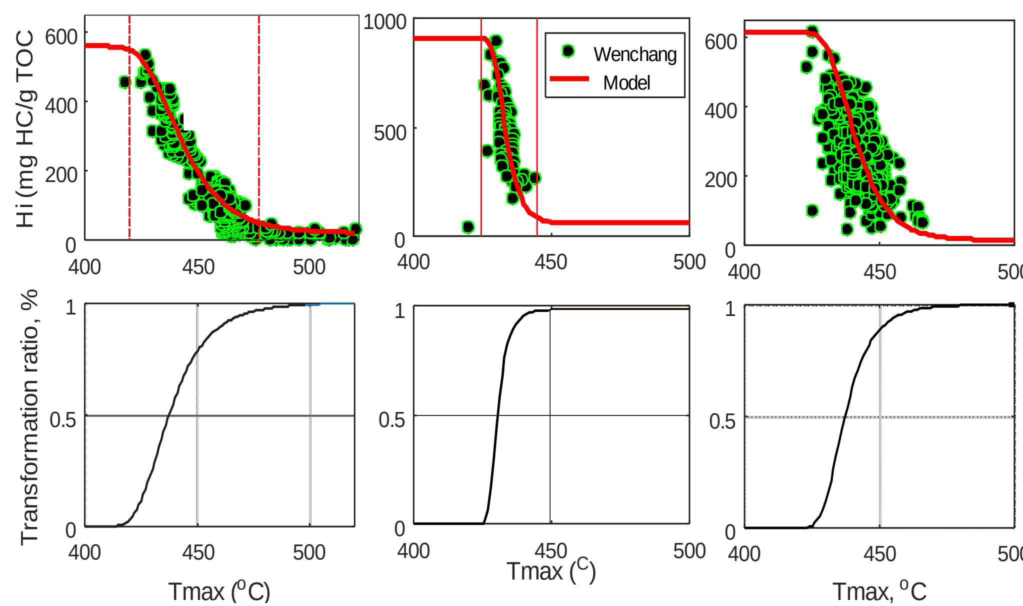




Interpretation of SR kinetics from Rock-Eval pyrolysis data

- Broad generation (Tmax) window indicates kerogen with variable activation energies, due to internal complexity or heterogeneity at molecular level in kerogen
- Narrow generation (Tmax) window indicates unitary kerogen kinetics
- Large data cluster indicates a mixed kerogen group of similar generation capacity, but variable reactivation energy, resulting from temporal and spatial variation of organic facies or source of inputs

Fm	β	θ	initial HI	C
Canol	438	-34	540	25
Wenchang	432	-120	850	50
2WS, West	438	-55	600	15



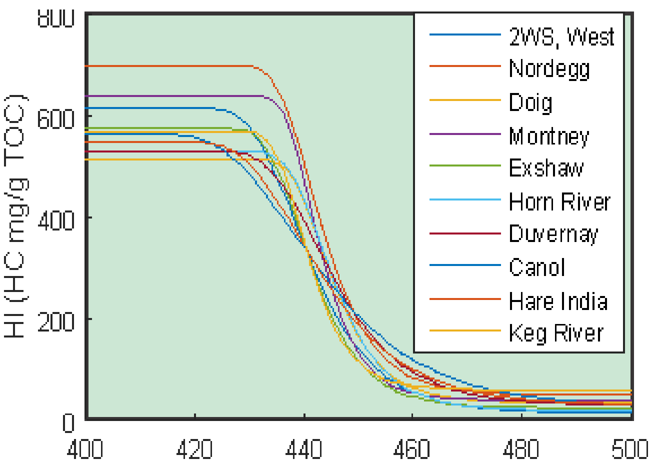
Devonian marine SR
Canol Fm, WCSB

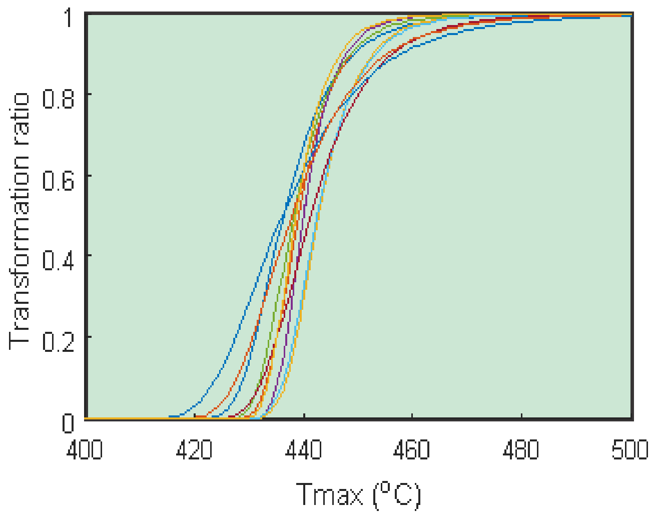
Eocene lacustrine
Wenchang, PRMB

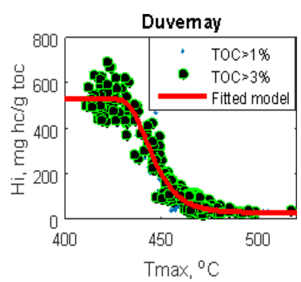
Cretaceous open marine
2WS Shale, WCSB

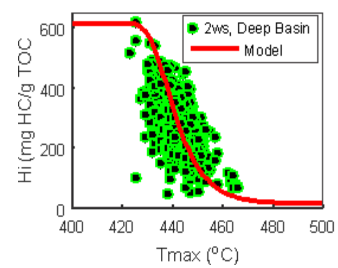
Marine Examples WCSB and Mackenzie Corridor

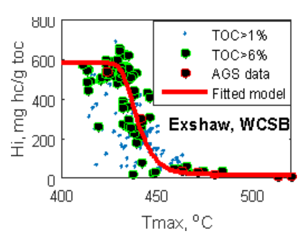
- 10 source rocks examined in WCSB
- Devonian to Cretaceous of age
- All marine settings
- Type II kerogen with 700< initial HI >500 HC mg/g TOC
- Variable Tmax windows for kerogen thermal decomposition
- HC generation starts @ Tmax: 420 to 435°C
- HC generation ends @ Tmax: 460 to 480 °C
- HC generation window spans from 30 to 60 °C

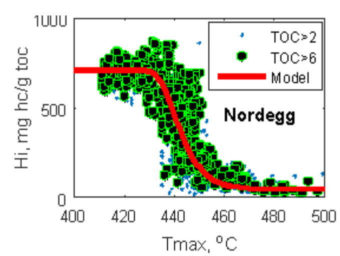


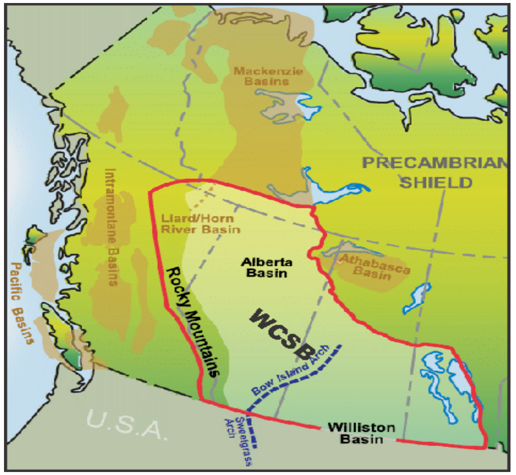












Summary

- Dimensionless plot of TOC-S2 eliminates the impact of maturity variation on data interpretation so that
  - samples of the same rock unit fall along a single line regardless their maturity
  - intercept indicates the percentage of inert organic carbon in initial TOC
  - the distance from initial point measures the thermal maturity
- The data-driven model can be used to assist Rock-Eval data interpretation for determining
  - a) whether the data under study come from a single source rock unit,
  - b) the maturity level,
  - c) characteristics of the hydrocarbon generation kinetics, such as onset and end of massive generation, and
  - d) the complexity of kerogen composition
- Same type of kerogen may have different generation kinetics: onset and end of generation windows (Tmaxs), and kerogen decomposition rate, as revealed by data from various source rocks in Canadian sedimentary basins

Key references

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Acknowledgments

- GNES program of Geological Survey of Canada for supporting this study
- Dr. Xiaojun Liu for helping the pyrogram inversion
- Dr. Mark Obermayer for retrieving the archived pyrogram data

Thank you

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Questions