

# **PS Breaking Down Barriers in Mudstone Investigations: What Oil Shale Can Tell Us About Shale-Hosted Hydrocarbons\***

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## **Abstract**

Production of shale oil and associated gas from oil shale requires artificial heating of immature kerogen, either at the surface or in situ. Development of oil-bearing shale and gas shale depends upon more traditional methods, although applied in more complex ways to kerogen that ranges from incipiently mature to overmature. However, the rocks themselves are strikingly similar, even in their compositional and textural diversity. All are very tight, impermeable mudstone (and siltstone), and production of the hydrocarbons, whether natural or synthetic, depends upon fracturing the rock to drain the products. There are, therefore many ways in which understanding of the properties of the broad class of rocks informally called shale can be complementary. The industrial divide between historic shale oil (mined and retorted) and new shale-hosted oil (drilled and produced) should not inhibit mutual understanding.

Three major linked areas of investigation are critical to understanding the variations in behavior of reservoirs in these diverse rocks: (1) Rock Mechanics - properties measured across a range of temperatures and pressures are needed to describe mechanisms of generation, migration and trapping of oil and gas, and to understand the fracturing behavior of the rock for field development, (2) Chemical Kinetics - understanding generation of hydrocarbons requires experimentation and modeling at temperatures in the range of in situ retorts, so that these experiments are important to understanding both synthetic and natural systems, (3) Petrology and Paragenesis - behavior of shale depends not only on its organic content, but also on its mineralogic composition and the variability of that composition. These properties in turn result from the history of the sedimentary rocks, the depositional environments under which they formed, and the diagenetic alteration that followed their deposition.

We have developed three separate research consortia on shale/mudstone systems. Common ground for each of these consortia include:

- 1) Characterization of sedimentologic and petrologic features to create an integrated geologic framework,
- 2) Measurement of critical properties relating to seismic characterization, rock strength and fracturing behavior,
- 3) Modelling of rock mechanical behavior under stress.

Understanding shale systems generically can provide synergistic insights across plays.



## Abstract

Production of shale oil and associated gas from oil shale requires artificial heating of immature kerogen, either at the surface or in situ. Development of oil-bearing shale and gas shale depends upon more traditional methods, although applied in more complex ways to oil and gas derived from kerogen that ranges from incipiently mature to overmature. However, the rocks themselves are strikingly similar, even in their compositional and textural diversity. All are very tight, impermeable mudstone (and siltstone), and production of the hydrocarbons, whether natural or synthetic, depends upon fracturing the rock to drain the products. There are, therefore many ways in which understanding of the properties of the broad class of rocks informally called shale can be complementary. The industrial divide between historic shale oil (mined and retorted) and new shale-hosted oil (drilled and produced) should not inhibit mutual understanding.

Three areas of investigation are critical to understanding behavior of reservoirs in these diverse rocks:

- 1) **Rock Mechanics** – properties measured across a range of temperatures and pressures are needed to describe mechanisms of generation, migration and trapping of oil and gas, and to understand the fracturing behavior of the rock for field development.
- 2) **Chemical Kinetics** – understanding generation of hydro-carbons requires experimentation and modeling at temperatures in the range of in situ retorts, so that these experiments are important to understanding both synthetic and natural systems.
- 3) **Petrology and Paragenesis** – behavior of shale depends not only on its organic content, but also on its mineralogic composition and the variability of that composition. These properties in turn result from the history of the sedimentary rocks, the depositional environments under which they formed, and the diagenetic alteration that followed their deposition.

Our research on shale/mudstone systems has focused on common ground in these areas:

- 1) Sedimentologic/petrologic characterization to create an integrated geologic framework
- 2) Measurement of properties critical to seismic character, rock strength & fracturing behavior
- 3) Modelling of rock mechanical behavior under stress

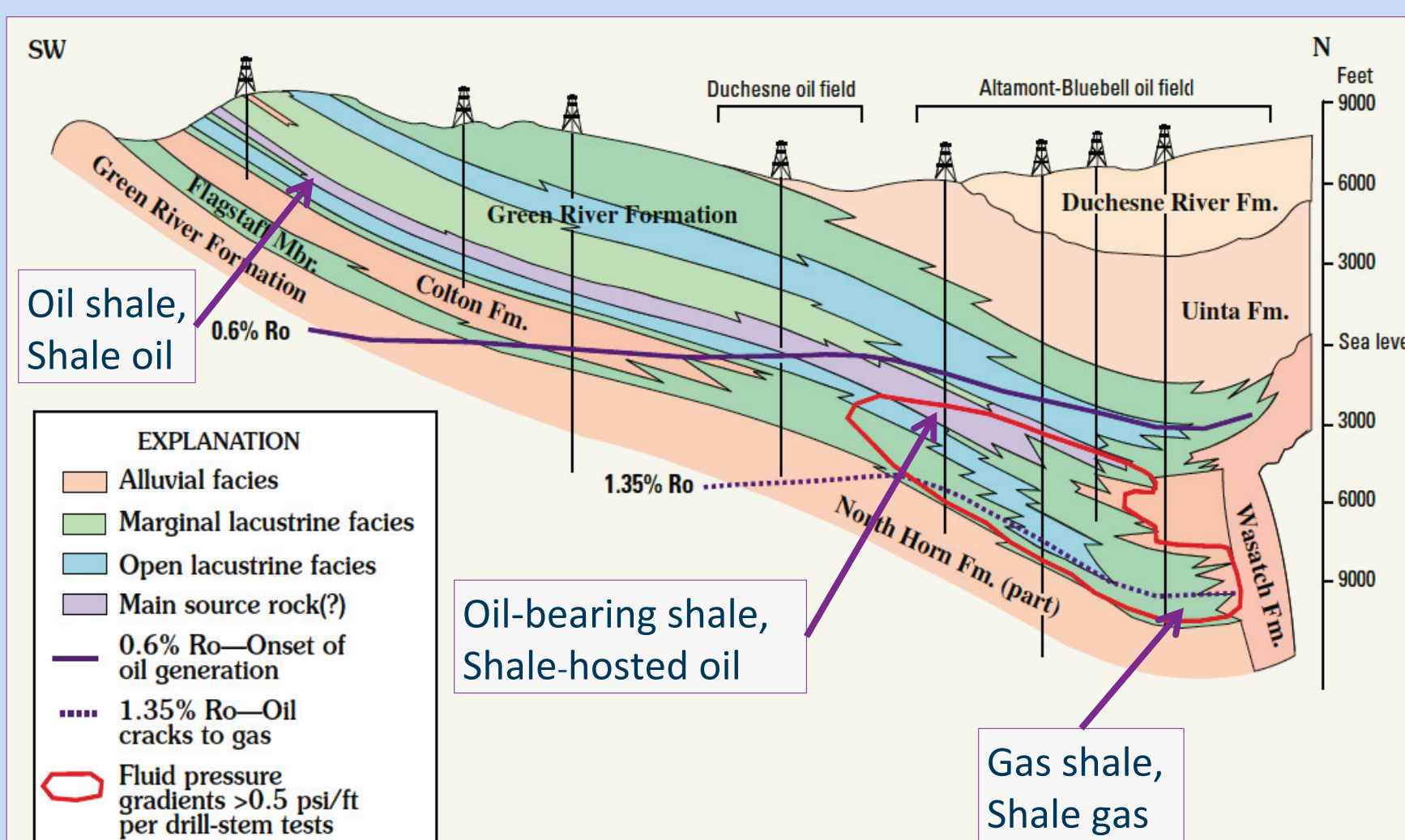
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## Introduction: Hydrocarbons in shale and mudstone

- Steady demand & new technology drive interest in turning source rock formations into reservoirs
- Mudstone or shale, organic richness is key
- Seeking hydrocarbons that have not migrated far from their sources
- What can oil shale development add to the conversation?

## Relationship of closely related shale and mudstone hydrocarbon deposits



The terms *oil shale* and *shale oil* have been applied for more than one hundred years (see references below) to, respectively, fine-grained immature organic-rich mudstone, marlstone and siltstone, commonly of lacustrine or marine origin, and to the liquid hydrocarbon produced by pyrolysis in a retort. It is appropriate to recognize the priority of this application of these scientific terms, despite a great deal of discussion of the composition of these rocks. (See box to right for detailed mineralogic characteristics of rocks now called shale.) We suggest substituting *oil-bearing shale* and *shale-hosted oil* for fine-grained formations that contain liquid hydrocarbons, to avoid continued confusion.

- BEILBY, G. T. (1897) Thirty Years' Development in the Shale Oil Industry. J. Soc. Chem. Ind., 18, 876886.
- IRVINE, R. (1894) Shale Oil Industry. J. Soc. Chem. Ind., 13, 1039-1044.
- TAYLOR, ANDREW (1873) On Bitumen, Oil Shales and Oil Coals. Edinburgh Geol. Soc. Trans., 2, 187189.
- VALENTINE, G. A. (1890) Carbonaceous Mineral or Oil Shale from Brazil. South Wales Inst. Eng. Proc., 17, 20-28.

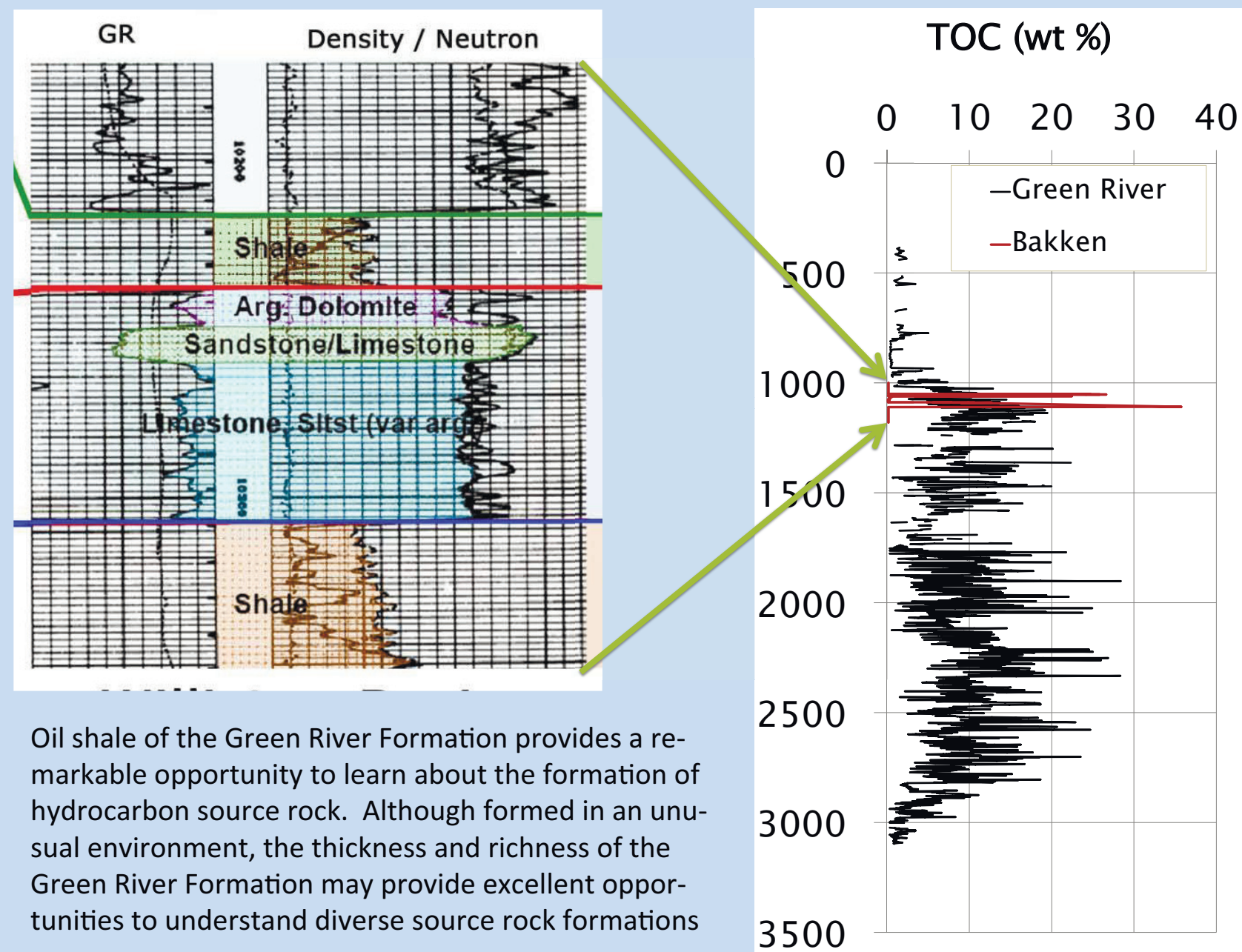
Source - USGS, Petroleum Systems and Geologic Assessment of Oil and Gas in the Uinta-Piceance Province, Utah and Colorado



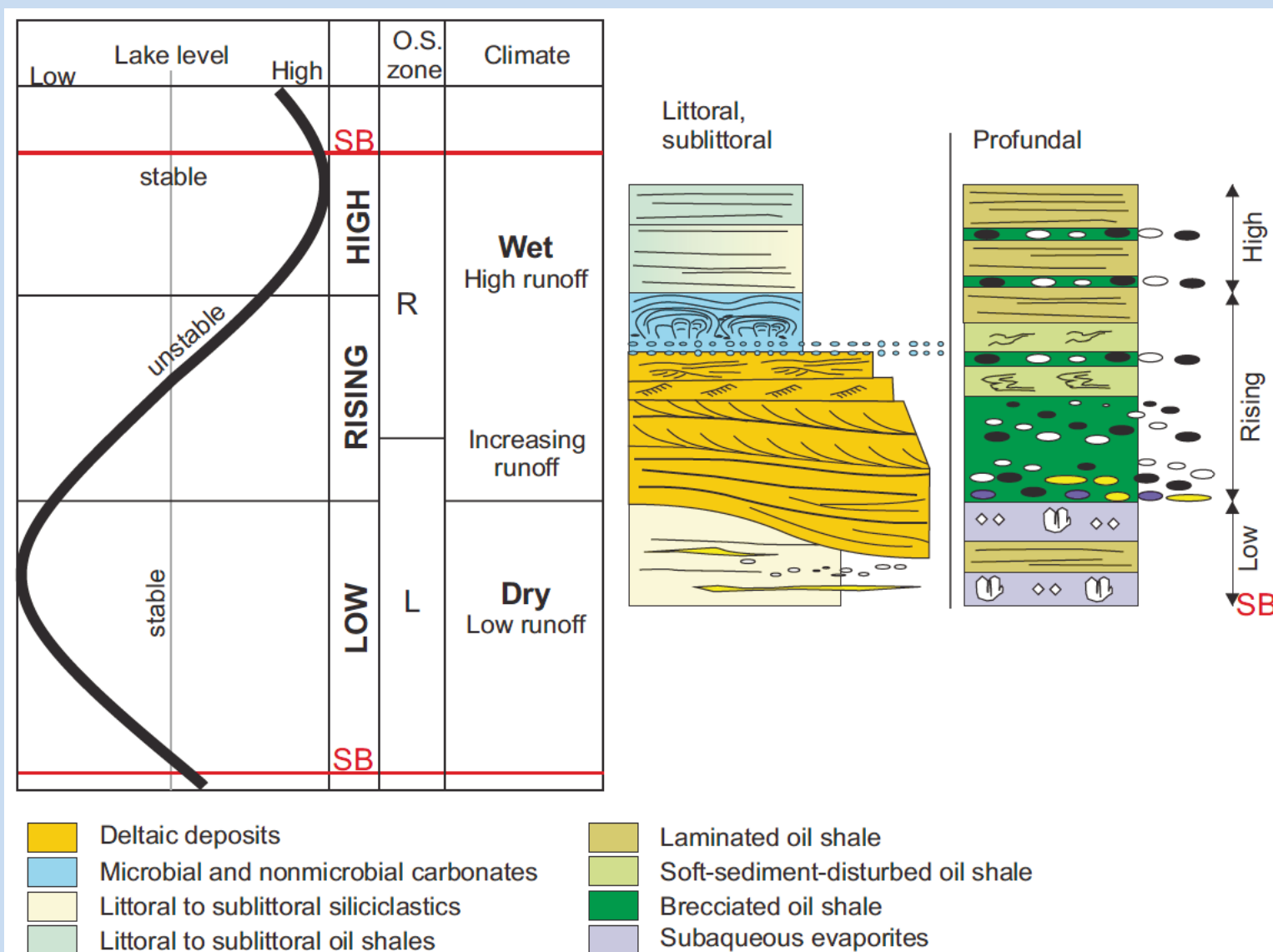
# Breaking Down Barriers in Mudstone Investigations:

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## Bakken – Green River comparison



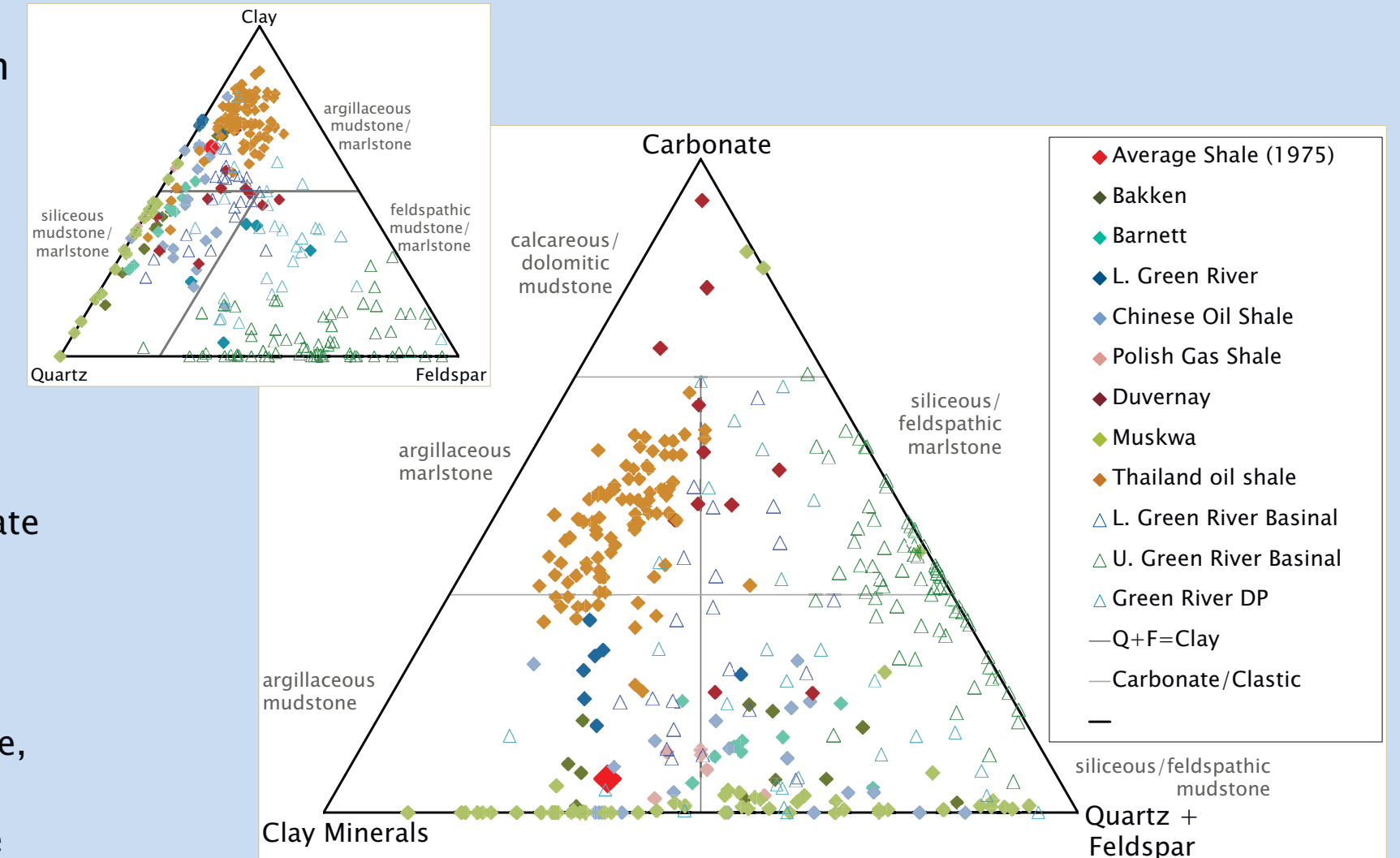
## Sequence stratigraphic framework for organic richness



Our group has defined a sequence stratigraphic framework for the lacustrine Green River Formation that connects well to the long-defined rich and lean zones important to oil production (Tanavsuu-Milkeviciene et al 2012). Organic rich zones are deposited during rising and high lake levels as a result of a balance of productivity and preservation, as well as dilution by both evaporitic and clastic sediment.

## Shale and mudstone composition varies widely

- Samples from global hydrocarbon and oil shale deposits show mineralogic diversity
- Most lie away from the clay-rich Average Shale of Pettijohn (1975) toward mineral groups likely to increase brittleness
- Mudstone categories not well defined
  - Marlstone – mudstone with carbonate to clastic (clay mineral + quartz + feldspar) between 1/3 and 2/3
  - Green River Formation oil shale includes argillaceous, siliceous, and feldspathic mudstone and marlstone, all containing Fe-dolomite
- Unusual, and in some cases, unique



## Physical properties of shale/mudstone systems

Source and reservoir are tight (impermeable) mudstone & siltstone (including marlstone and marly siltstone)

Production of hydrocarbons, natural or synthetic, depends on rock fracture systems to drain the products

- Natural fracture systems, potentially induced by hydrocarbon generation
- Hydraulic or explosive fracturing for production
- Heat-induced fracturing for in-situ oil shale development

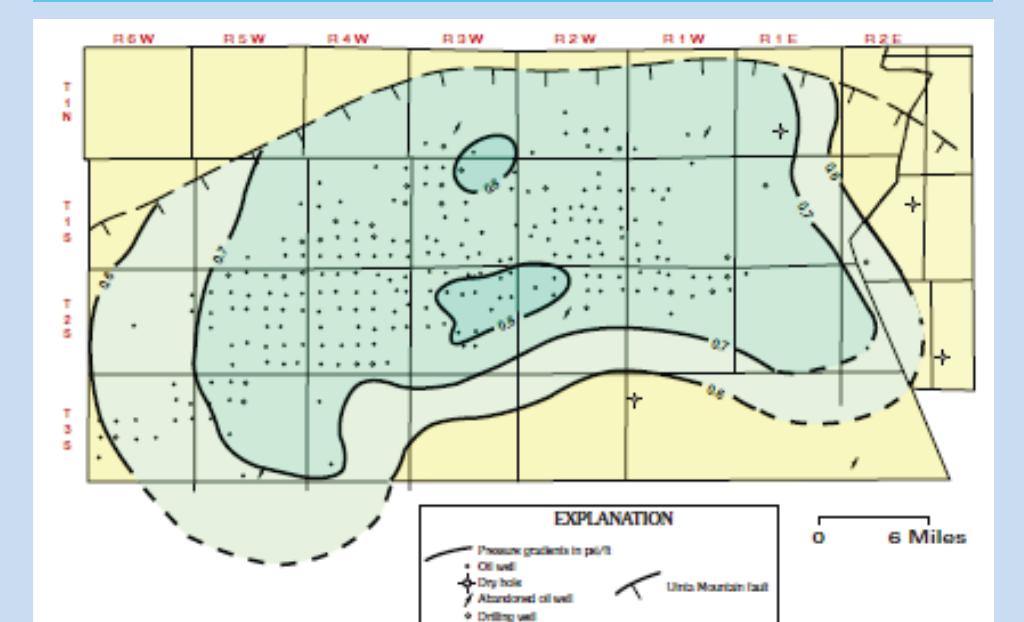
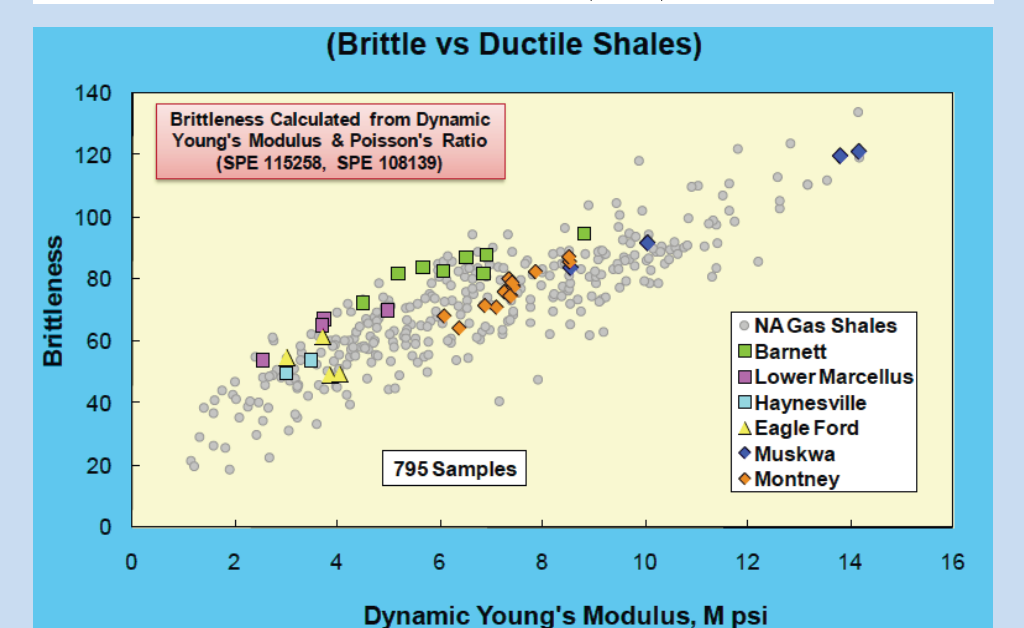
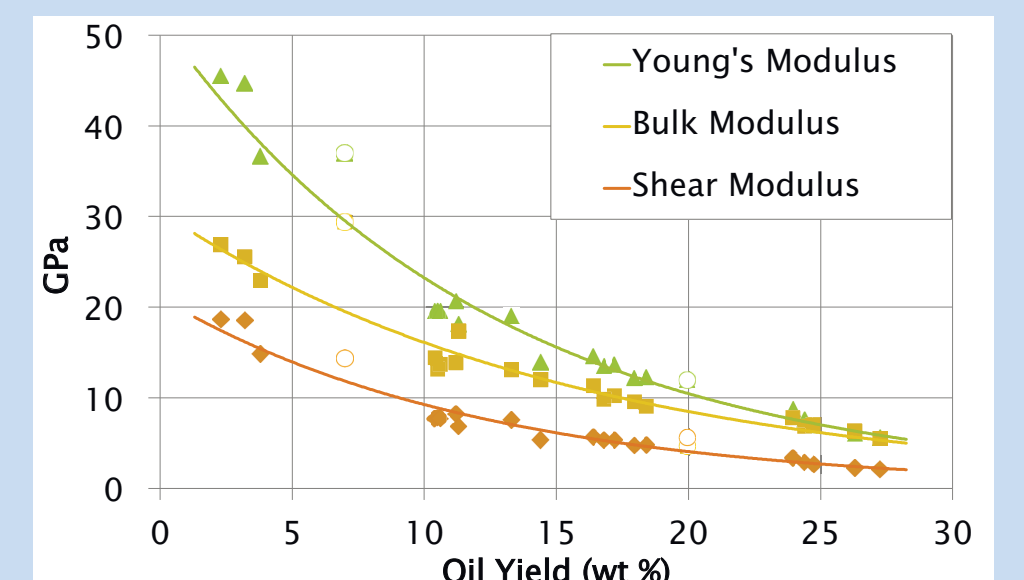
Properties measured across temperature and pressure range needed

- To describe mechanisms of generation, migration & trapping of oil & gas
- To understand fracturing behavior for field development

Properties important to the strength of the rock depend upon:

- Organic richness and possibly maturity
- Mineral composition (primarily clay-carbonate-framework silicates)
- Fabric – distribution of kerogen, lamination, porosity

Understanding properties of broad class of rocks informally called shale can be complementary





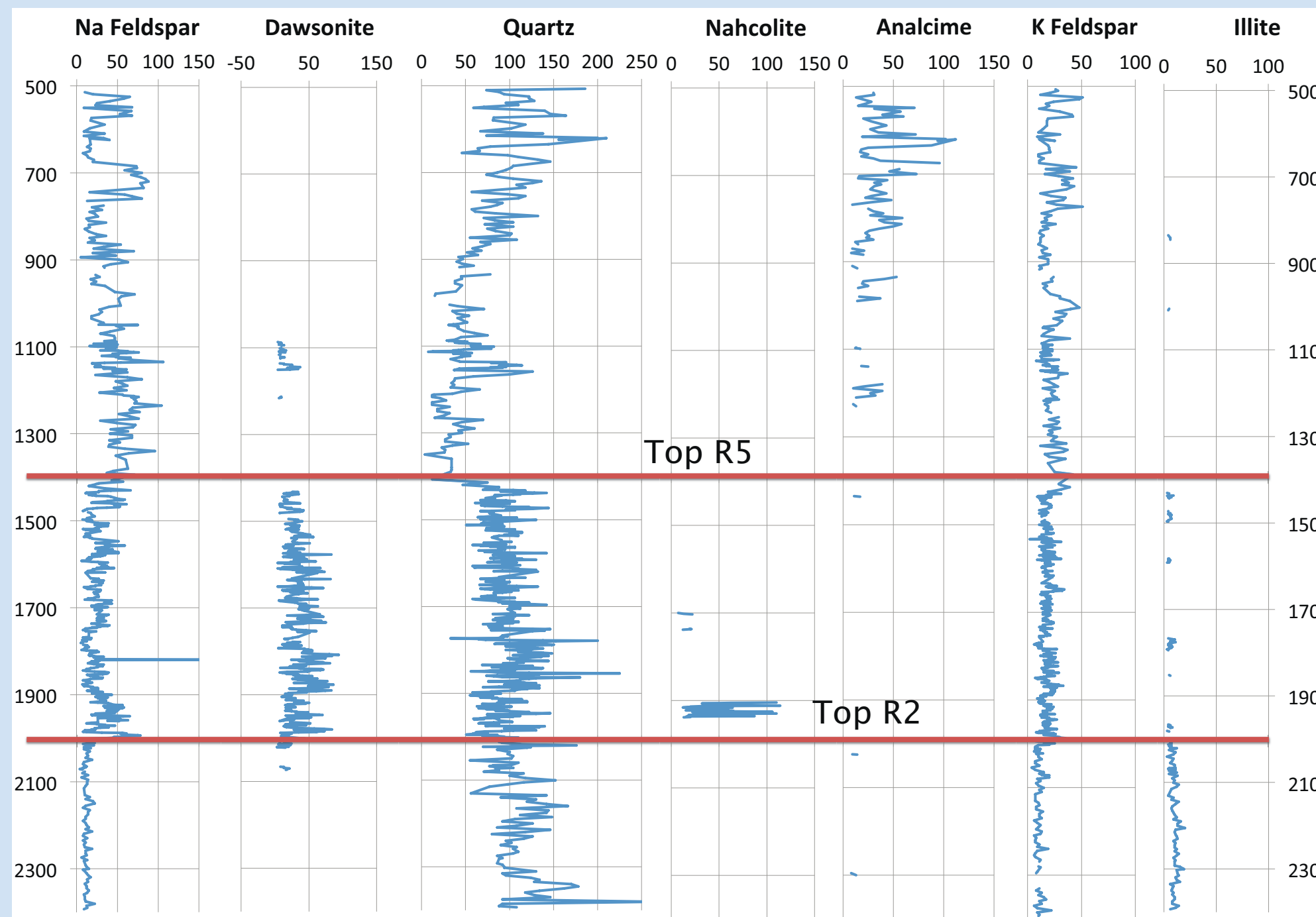
# What Oil Shale Can Tell Us about Shale-Hosted Hydrocarbons

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## Mineralogy reveals significant diagenetic events in US Geological Survey CR-2 well

Behavior of shale depends not only on its organic content, but also on mineralogic composition and variability of composition. These properties in turn reflect the sedimentary history of the rocks, depositional environments under which they formed, and diagenetic alteration that followed deposition.

Chemical variations that are unusual, even extreme with respect to **salinity, alkalinity, and redox potential** may reveal features that connect, for example, lacustrine and marine sedimentary systems.



## Oil generation experiments at short and long time scales

### Oil API Decreases with Heating Rate

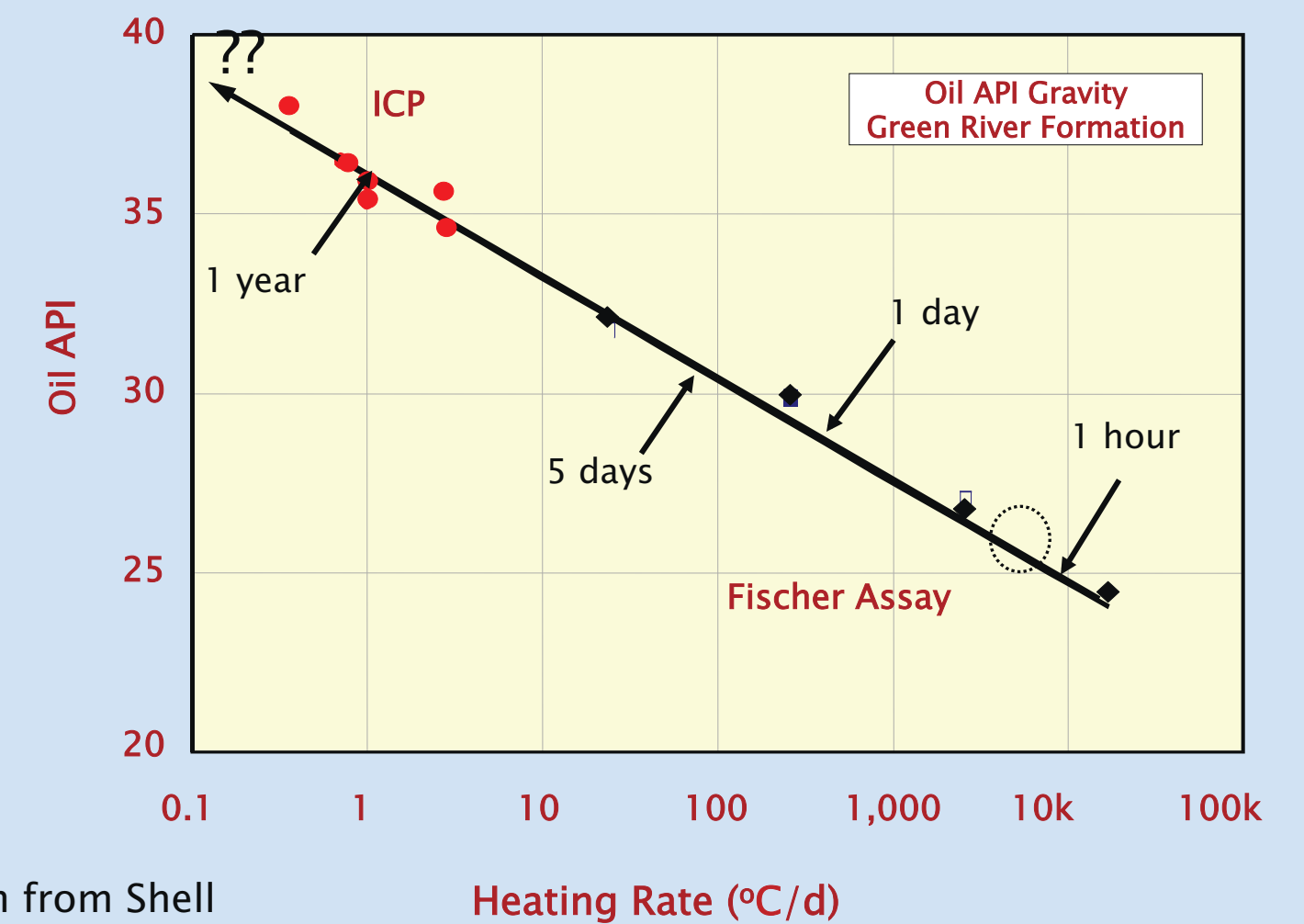


Diagram from Shell

Understanding the kinetics of generation requires experiments at temperatures in the range of in situ retorts, so that these experiments are important to understanding both synthetic and natural systems.

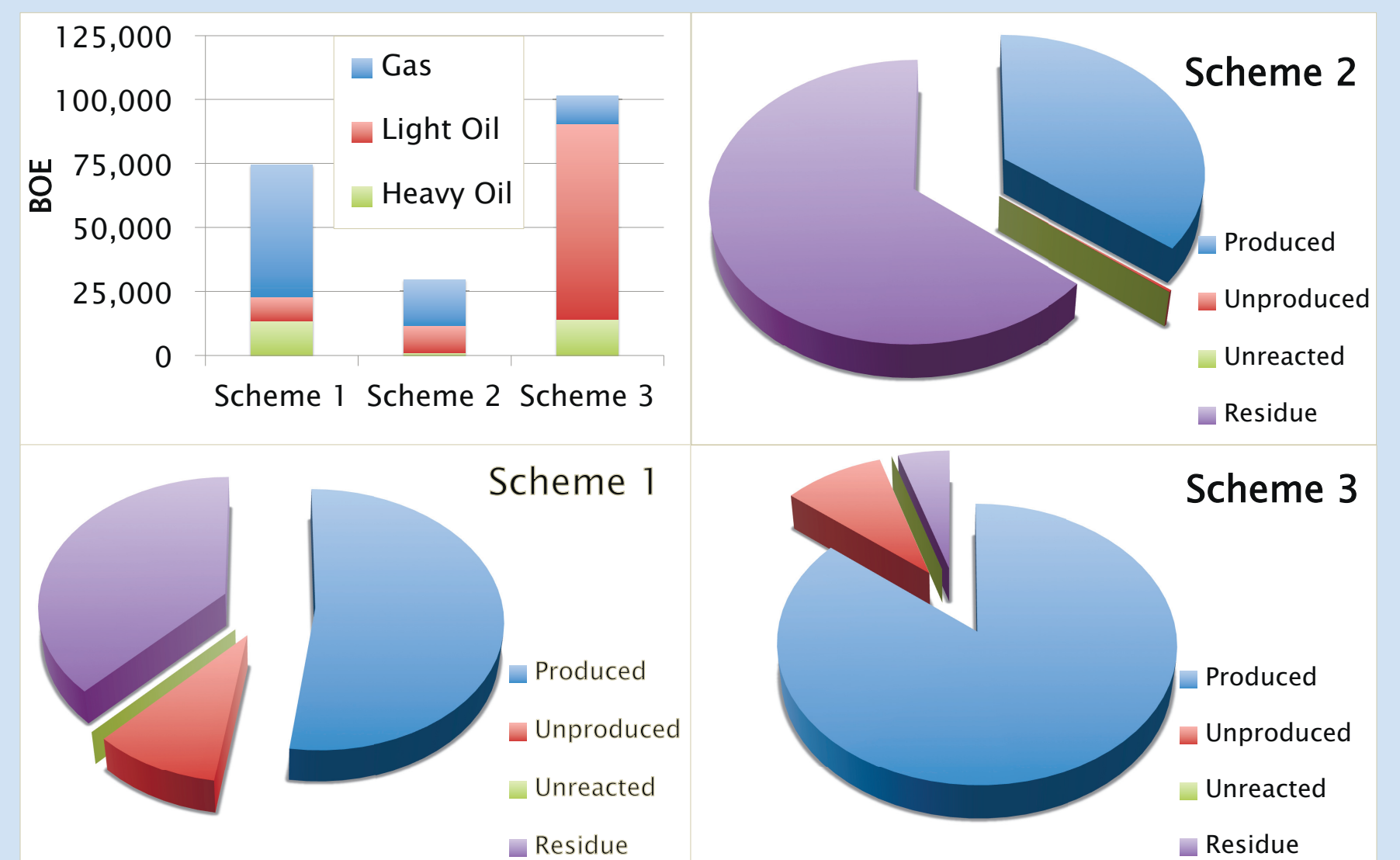
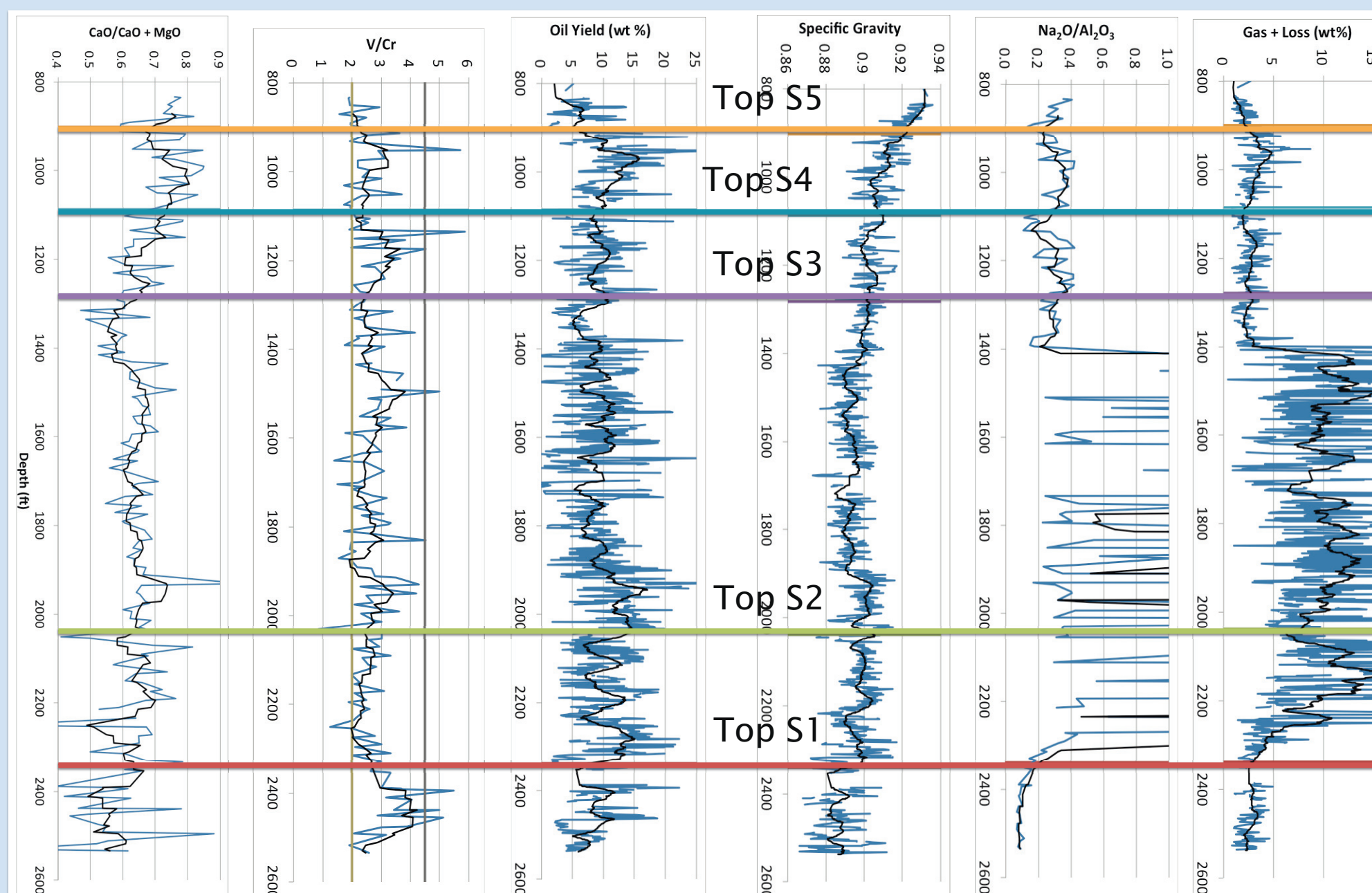
Analytical and experimental measurements give some indication of kinetic behavior of kerogen on heating, but significant diversity in kinetic models and results remain. Do we have a full appreciation for the uncertainties in our understanding of the kinetics of kerogen conversion?

Three different kinetic schemes developed to model in situ oil shale production show startling differences in the yield, product mix, and degree of reaction of oil shale. It does not appear that these schemes converge at long times.

## Chemistry reveals significant relationships and events in US Bureau of Mines 01a well

Basin center mudstone and shale of the Green River **contain Fe-dolomite** as the dominant divalent carbonate, even early in lake history, supporting the concept that early chemical stratification enabled preservation under reducing conditions. Do these conditions apply to marine organic shale?

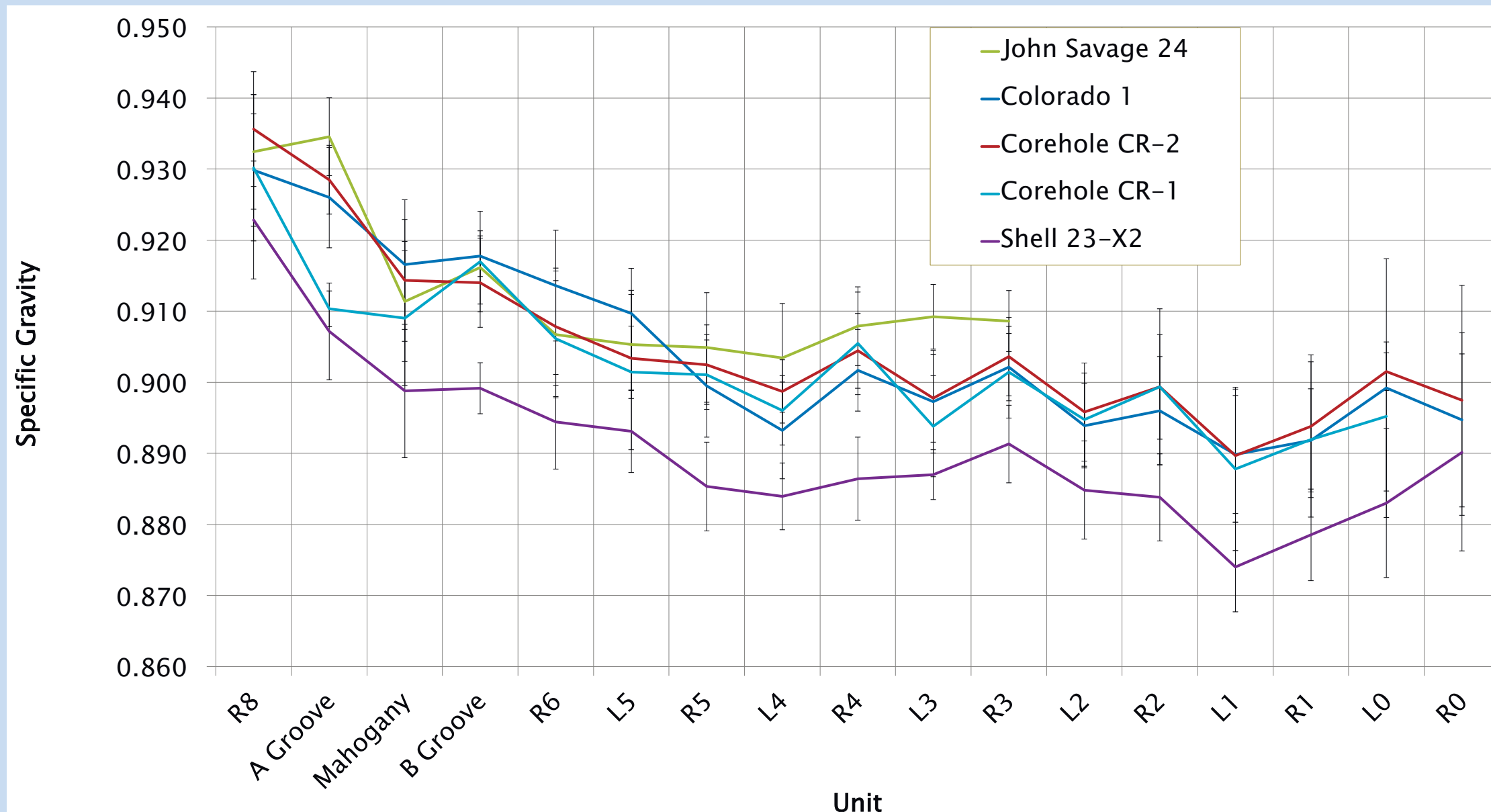
Does destruction of clay and deposition of dawsonite reflect an extreme version of diagenesis associated with chemical stratification potentially observable elsewhere?





# An additional observation and some conclusions

## Fischer Assay data show significant diversity of kerogen composition



Fischer Assay data from rich oil shale show compositional diversity within source rocks of a single type (Type I kerogen). These patterns are visible here because of the large numbers of samples run by a standard technique.

Further investigation of this variation may reveal significant insight into lacustrine and possibly other organic matter types.

Specific Gravity	API Gravity
0.95	17.5
0.90	25.7
0.85	35.0

## Conclusions

- Understanding shale systems generically can provide synergistic insights across plays
- Integrated analysis pays general benefits
  - Even of unusual basins like the Green River Formation basins
  - Sedimentologic and chemostratigraphic connections between lacustrine and marine systems
  - Some oil shale basins of ambiguous origin
- Stratigraphic, mineralogic, chemical characterization supports engineering property determination
- Kinetic models have yet to capture fully behavior across T and time scales
- We have developed three research consortia on shale/mudstone systems
  - Green River Formation oil shale
  - Bakken shale-hosted oil play
  - Niobrara limestone/marlstone-hosted oil play
- Common ground for each of these consortia include:
  - characterization of sedimentologic and petrologic features to create an **integrated geologic framework**
  - **measurement of critical properties** relating to seismic characterization, rock strength and fracturing behavior
  - **modeling of rock mechanical behavior** under stress

