Shale Gas Geochemistry
Program Design and Interpretation Services

Part I : Geochemical Program Design Services

What are the questions you need to answer?

Your sampling and analysis program will be designed to address prospect- and play-specific critical risk factors. When designing a program, you may consider such things as:

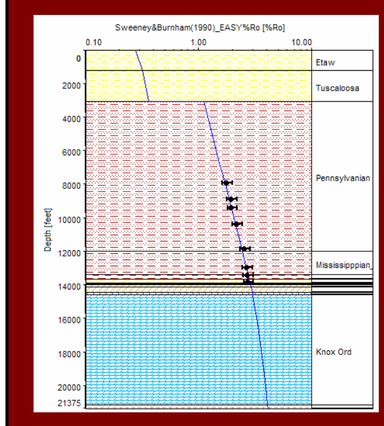
- Gas play type (biogenic, thermogenic or mixed)
- Source rock maturity
- Source rock richness
- Sorption/desorption characteristics
- Kerogen type
- Generation, expulsion and primary migration behavior
- Character and correlation of tested hydrocarbons

What to sample?

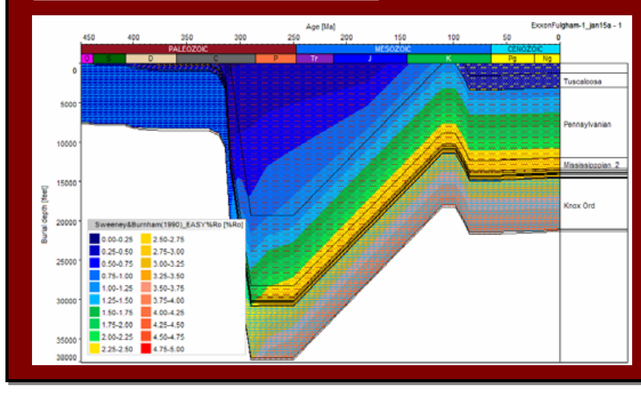
Depending on program objectives, logistics and cost constraints, appropriate materials for sampling might be cuttings, percussion/rotary SWC, core plugs, mud gas and produced or tested fluid samples. Sampling requirements depend on:

- Play maturity – Is it an unproven or high risk play, or has an empirical database been developed to relate key geochemical attributes to gas volumes and well performance?
- Play type – Biogenic gas? Thermogenic gas? Are associated liquids an upside or a potential well killer?

Who cares about the uphole section?



- Evaluating an immature shale gas play or extending an established play requires a full understanding of the geological context
- OilTracers can help you obtain the geochemical data necessary to complete your petroleum systems analysis



Calibrated maturity profile and burial history from the Exxon Fulgham #1 well in the Black Warrior Basin

Courtesy of Baseline Resolution, Inc.

BASELINE RESOLUTION INC.

Black Warrior Basin Geochemistry Study

Your well plan includes shale coring at an extraordinary cost

You want an assessment program to extract value from this core. Depending on your objectives, a likely value-adding component of assessment is a stepwise program of geochemical analysis. Such a program might consist of screening, follow-up and integrated analyses such as:

- Total organic carbon (TOC) screening analyses – amount of organic carbon in both core samples and uphole cuttings/SWC
- Rock-Eval – indirect indicator of type of organic material and source rock maturity – analyze both core samples and uphole cuttings/SWC
- Visual kerogen – *direct* indicator of type of organic material and source rock maturity – also analyze uphole samples selectively
- Extract GC – presence and character of associated petroleum liquids

Carbon isotopic composition of desorbed gases and mud gases

- Composition and isotopes of produced and/or tested gases
- Geochemical attributes of associated hydrocarbon liquids, if present

What analyses should be performed?

One of the most common mistakes in any geochemistry program is to 'boiler-plate" analyses. What works in one play or well will not necessarily be the optimal program for your upcoming well. OilTracers will help you design each analysis program:

- To plan for integration of geochemical, engineering and geological data
- To consist of initial lower-cost screening analyses that are followed only as needed by detailed analyses
- To include contingency analyses – expect the unexpected!

How to avoid under- and over-analysis?

Understand the data that are being acquired. A few examples:

- Even though maturity may be a critical risk factor, only a very few high quality vitrinite reflectance measurements may be necessary <u>through the objective</u> ⇒ augment these with maturity indicators up and downhole
- Rock-Eval analyses are typically done to assess maturity and remaining potential but are unreliable if organic carbon content is low ⇒ perform screening studies first, then select samples for follow-up analyses
- It may be a biogenic gas play or biogenic gas may be a risk ⇒ integrate the sampling program with desorption analyses and consider augmenting with mud gas data

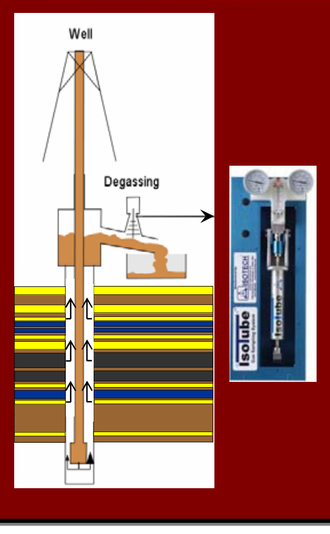
OilTracers will help you to interactively interpret the data as they are acquired so that stepwise analyses can be conducted.

Are there cost-effective ways to obtain additional data to help evaluate my well?

Short answer: <u>Yes</u>

- Mud gas analyses are one such additional sampling and analysis type to consider
- Composition and gas isotopes
- High resolution continuous record
- Provide additional data with which to assess:
  - Genesis of gas (e.g., biogenic vs. thermogenic)
  - Maturity of source rock that generated the gas
  - Continuity of accumulation
  - Containment

Ask us about mud gas and other methods to optimize your shale gas evaluation



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Shale Gas Geochemistry

Program Design and Interpretation Services

Part II : Geochemical Interpretation Services

How to obtain data of the highest quality?

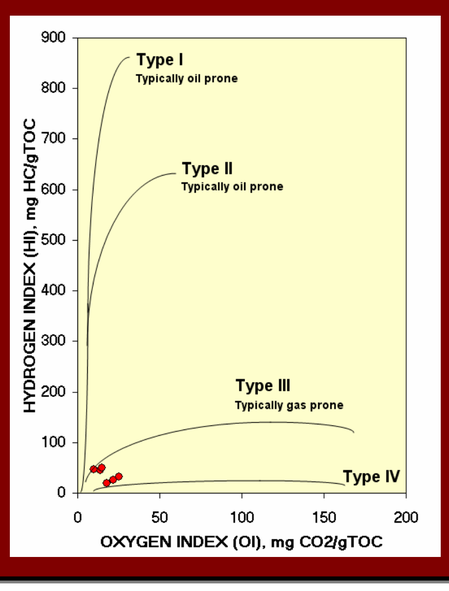
OilTracers provides services that enable clients to obtain data of the highest quality that are relevant to the program objectives. These services include:

- **Working directly with the vendors and laboratories to ensure that sampling and analyses are performed as planned**
- **Adjusting the sampling and analytical program as necessary based on screening data and/or unexpected results**
- **Providing QA/QC of the geochemical data**
- **Ensuring that the geochemical data acquired also help answer questions arising from engineering analyses**

OH NO! It was supposed to be a Type II source rock!

Widely used interpretation schemes constructed from Rock-Eval data can be misleading for high maturity samples.

In this HI-OI diagram example, samples from a post-mature gas-bearing shale had a reflectance of >1.3% Ro. Visual kerogen analyses showed the rock contained Type II oil-prone kerogen. However, this mature source rock has already generated its petroleum potential .... it plots as being a Type III/IV source rock because it has a remaining capacity to generate small amounts of dry gas.



Data obtained from mature samples require corrections in order to reconstruct their initial richness (TOC) and yield characteristics.

"Modified Van Krevelan" diagram showing kerogen type interpretation fields for immature source rocks

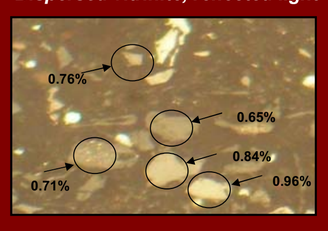
Courtesy of Baseline Resolution, Inc.

In many Shale Gas plays visual kerogen analyses are the Rosetta Stone …

.... without which source rock maturity, richness and generation characteristics can only be inferred.

- **A well-trained microscopist is needed to evaluate and measure vitrinite reflectance – the industry standard maturity indicator.**

Dispersed vitrinite, reflected light

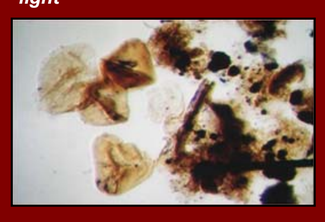


- **The microscopist will be able to use other maturity indicators that have been calibrated against vitrinite reflectance. The yellow orange color (TAI) of this trilete fern spore indicates a sample that is immature for generating oil from a Type II kerogen.**

Large fern spore, transmitted light

- **The relative abundance of individual macerals in a source rock provide information about the amount and type of products generated. The main constituents of this isolate indicate a mixed oil and gas-prone source rock.**

Mixed kerogen isolate, transmitted light



- **Successful predictive models relate organic geochemical attributes to source rock facies. For example, the oil-prone algal bodies (alginite) of Tasmanites provide direct evidence of a marine depositional environment.**

Tasmanites, fluorescent light

"Interpretation" services are not throwing data over the fence

We are well aware that in many cases the interpretation of geochemical data is not straightforward. Stand-alone interpretations are not usually particularly robust, especially in challenging plays. To get the most value from the geochemical data that are acquired we typically:

- **Interpret the geochemical data obtained from different types of samples and analyses *as a whole*, e.g., Rock-Eval, visual kerogen analyses, mud gas data, hydrocarbon fluid test data**
- **Integrate geochemical data with other data types acquired, e.g., wireline logs, petrographic analyses and stratigraphic models**
- **Perform petroleum systems modeling as needed to address questions arising out of well results**
- **Work closely with the asset team in order to extract the most relevant interpretations out of the data set**

In a perfect world.....

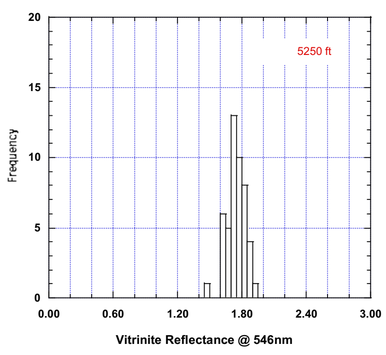
.... all maturity data would be as clear cut and unambiguous as in this example.

In the real world:

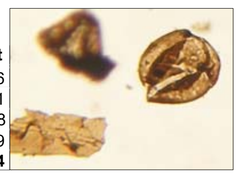
• Many Shale Gas petroleum systems contain little vitrinite or other materials used for maturity assessments.

• It is critically important in these cases to determine maturity from whole well profiles and to examine *multiple maturity indicators*.

Vitrinite Reflectance and Visual Kerogen Analysis Summary



00056	5250 ft
Minimum	1.46
Maximum	1.91
Points	48
Std Deviation	0.09
Mean	**1.74**



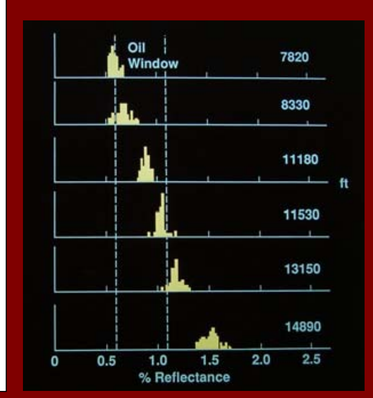
Comments: Organic matter in this sample consists of massive amounts of humic material (vitrinite and semi-fusinite) associated with very little amorphous debris. Vitrinite particles large enough to measure are common. Based on 48 measurements, the average Ro is 1.74%. Spores are very abundant and their very dark brown color (see photo) indicates a TAI value of about 3, which is consistent with the measured Ro of 1.74%. These data suggest the OM in this sample has just reached the post generation stage of thermal maturity for oil prone and wet-gas prone OM.

Ordered Ro Values

1.46	1.61	1.62	1.62	1.63	1.64	1.65	1.66	1.66	1.67	1.67	1.69
1.70	1.70	1.70	1.70	1.70	1.70	1.72	1.72	1.72	1.73	1.73	1.73
1.74	1.75	1.75	1.75	1.76	1.76	1.76	1.78	1.79	1.80	1.80	1.81
1.81	1.81	1.82	1.82	1.83	1.83	1.84	1.85	1.88	1.88	1.90	1.91

Visual Kerogen Analysis

Client ID	Sample ID	Depth	% Alg.	% Lip.	% Vit.	% Inert.	Liptinite Fluores.	% Oil Prone	% Gas Prone	TAI	%Solid Bit.	Pollen/ Spores
USA #1	00056	5250 ft		10	40	50	none	10	40	3		common

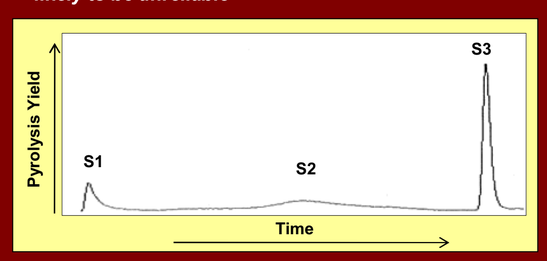


I can't reconcile the Rock-Eval data with what I know about the play ... what's going on?

Rock-Eval data provide indirect indicators of source rock maturity and remaining generative capacity. However, their interpretation are not always straightforward. For example, problems arise due to:

- ***High maturity* or low organic content source rocks that do not generate enough hydrocarbons to provide a meaningful Tmax value**
- **Drilling mud additives such as lignite, and cavings from the up-hole sections**
- **Indigenous petroleum (e.g., solid hydrocarbons) and migrated hydrocarbons**

The broad low S2 peak shown in the Rock-Eval pyrogram of this sample suggests that the Tmax value (defined as the temperature at which S2 elutes) is likely to be unreliable



We *always* recommend examining the raw data (not relying on the computer-generated Tmax values) and integrating the Rock-Eval data with direct maturity indicators (e.g., visual kerogen data) and ancillary geochemical information (e.g., gas isotopes).

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