

Upper Jurassic, Tampico-Misantla Basin, Onshore Mexico: Unconventional Resource Potential*

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Abstract

In the Gulf Coast of the U.S.A. and Mexico as well as offshore in the Gulf of Mexico Jurassic sediments are key source rocks supplying petroleum to conventional reservoirs. However, these source rocks also have demonstrated large unconventional reserves onshore USA due to retention of considerable portion of petroleum. Any unexpelled petroleum undergoes additional cracking to volatile oil, NGLs, and dry gas with further maturation. The Tithonian Pimienta Shale onshore Mexico shows comparable characteristics to highly successful shale oil and shale gas plays in North America.

The quantity and quality of organic matter in the Pimienta Shale is sufficient for high volumes of petroleum generation and retention. Initial or original TOC and relative hydrogen contents translate into retained petroleum potentials of approximately 70 mmboe/section at 1.00%Ro in the heart of the volatile oil window. Thicknesses are variable but several hundred feet are typical. With further maturation the retained petroleum in the Pimienta is cracked to gas at about 50% efficiency. At dry gas window maturity, this translates into about 200 bcf/section.

At lower thermal maturities the petroleum composition inhibits production from the shale itself. This is due to the petroleum composition which has elevated polar compounds. These compounds are undergoing cracking in the oil window, resulting in higher quality oil with increased pressure, i.e., better producibility. At lower thermal maturities, juxtaposed, non-source lithofacies may be a tight-oil play possibility where expelled petroleum has enhanced quality due to expulsion fractionation. Expelled oil will have lower polar constituents of petroleum than retained oil, resulting in a shift of API gravity of 5-10°API.

This, along with the adsorptive affinity of kerogen, explains why the source rock itself, despite containing high volumes of oil, is not necessarily a good shale oil prospect.

Oil saturation indices are variable but commonly show oil crossover effect, which is indicative of producible petroleum. Interestingly these intervals are commonly in the most brittle rocks with high carbonate contents. Of samples showing crossover, the average carbonate content is over 50%. As such, carbonates are not only brittle but have lower retention affinities, thereby enhancing producibility.

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Worldwide Geochemistry

TCU Energy Institute

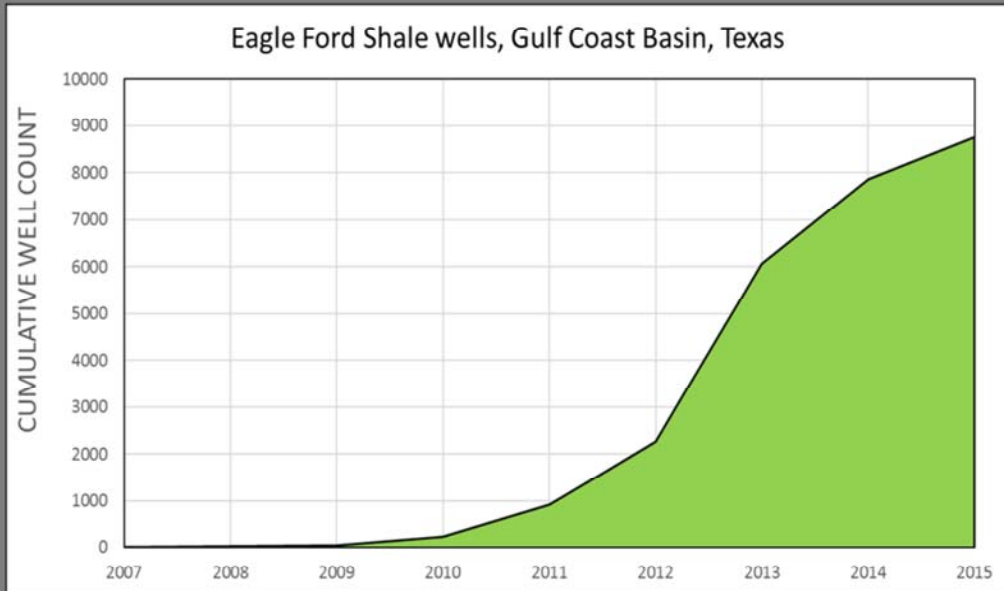
John Smyth

Halliburton Mexico City

Outline

- Background
- Unconventional U. Jurassic Potential Onshore Tampico-Misantla Basin
 - Petroleum Generation Potential
 - Retained Petroleum
 - Relationship of Thermal Maturity to Product Type
 - Primary vs Secondary cracking
 - Prediction of oil quality
 - Prediction of petroleum phase
- Synopsis
- Tribute

Unconventional Scale of Drilling: 8,745 wells in Eagle Ford since 2007



This graphic provides an indication of the number of wells needed to have an impact on national oil production in the USA. It will take similar numbers of wells in Mexico to impact the national economy.

Data source: IHS US Data Online

Shale Oil Resource Systems

- Naturally fractured shale – high porosity, permeability
 - Monterey shale
 - U. Bakken Shale
- Tight shales – low porosity, low permeability
 - Eagle Ford Shale
 - Wolfcamp Shale
 - Barnett Shale
- Hybrid Systems – organic-lean, tight rocks juxtaposed to organic-rich shales
 - Middle Member of Bakken Formation
 - Niobrara carbonate benches

There are three types of shale oil resources: (1) naturally open-fractured shale; (2) tight organic-rich shales; and (3) hybrid systems where an organic-lean interval is juxtaposed (overlying, interbedded, or underlying) to an organic-rich shale.

The term 'shale' is used in a general sense even for carbonate source rocks, such as the Eagle Ford Shale. The term mudstone could be substituted.

The U. Bakken Shale has produced oil since the late 1980s-1990s from an open fractured network. These wells are characterized by high initial flow rates with fast depletion.

The Barnett Shale is the prototypical tight shale with high TOC and high biogenic quartz content. It is perhaps the most difficult oil to flow.

The Eagle Ford and Wolfcamp can be considered tight shale or hybrids due to rock matrix particularly carbonate content; however they are tight 'shales' requiring high energy stimulation.

The Middle Member of the Bakken formation is a prototypical hybrid system where oil is expelled from the overlying and underlying organic-rich shales into the Middle Member that is organic-lean.

Generalized Location and Stratigraphic Column



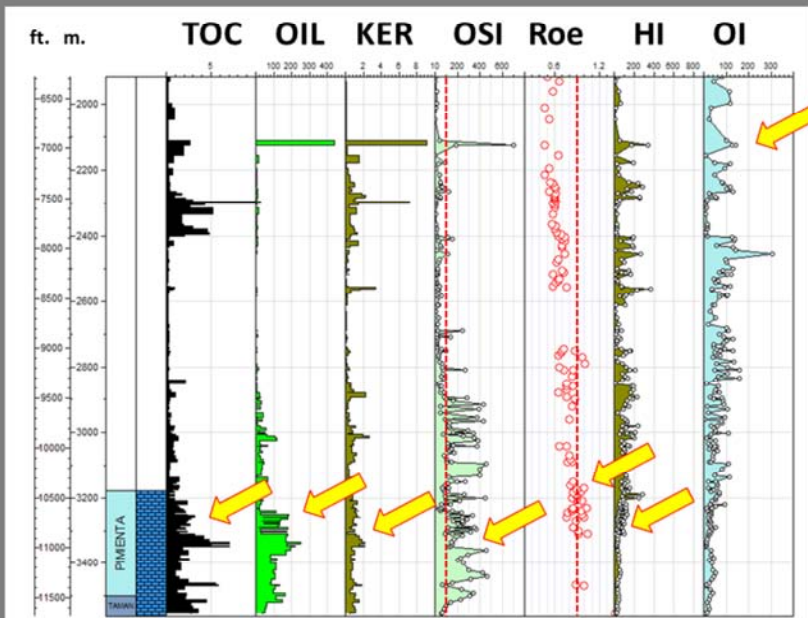
Conventional
Production
Intervals

U. Jurassic	Tithonian	Pimienta		
	Kimmeridgian	Taman	Chipoco	San Andres
	Oxfordian	Santiago	Zuloaga	Constituciones

East Texas equivalents: Bossier, Haynesville, Smackover
Deepwater equivalents: US Gulf of Mexico

System, Series, Stage	TAMPICO & TUXPAN AREAS
PLEISTOCENE	Alluvium
PLIOCENE	
NEOGENE	
MIocene	Tuxpan Escobal Coatzacoatlán
OLIGOCENE	Palma Real
Eocene	Velasco
PALEOCENE	Chicontepec
CENOZOIC	
UPPER CRETACEOUS	
Maastrichtian	Méndez
Campanian	
Santonian	San Felipe
Coniacian	
Turonian	Agua Nueva
Cenomanian	
LOWER CRETACEOUS	
Albian	El Abra Tamazunchale Tamazunchale
Aprian	Otates
Barremian	Tamaulipas interior
Hauterivian	
Valanginian	
Berriasian	
Tithonian	Pimienta
Kimmeridgian	Taman
Oxfordian	Santiago
Callovian	
Bathonian	Cahuasas
Bajocian	
MIDDLE JURASSIC	

Geochemical Logs of well penetrating U. Jurassic



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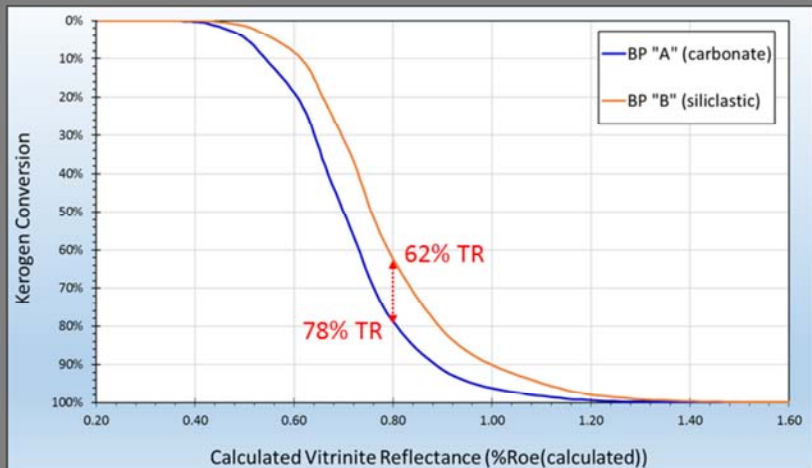
This geochemical log shows the following:

1. High TOC in the U. Jurassic, but also good TOCs in Cretaceous intervals.
2. The oil contents (based on S1) are very high in the U. Jurassic and select intervals just above it.
3. The kerogen content is low in this well as shown by S2 and HI based on the higher thermal maturity at about 1.00%Ro
4. The Oil Saturation Index (OSI) shows oil crossover indicative of potential production in the U. Jurassic and L. Cretaceous
5. There is a consistent trend in thermal maturity based on Tmax equivalent vitrinite reflectance
6. The OI values are much higher above the U. Jurassic, indicative of a mixed oil – gas prone system.

Comparison of Rates of Decomposition: Marine carbonate vs siliciclastic shale

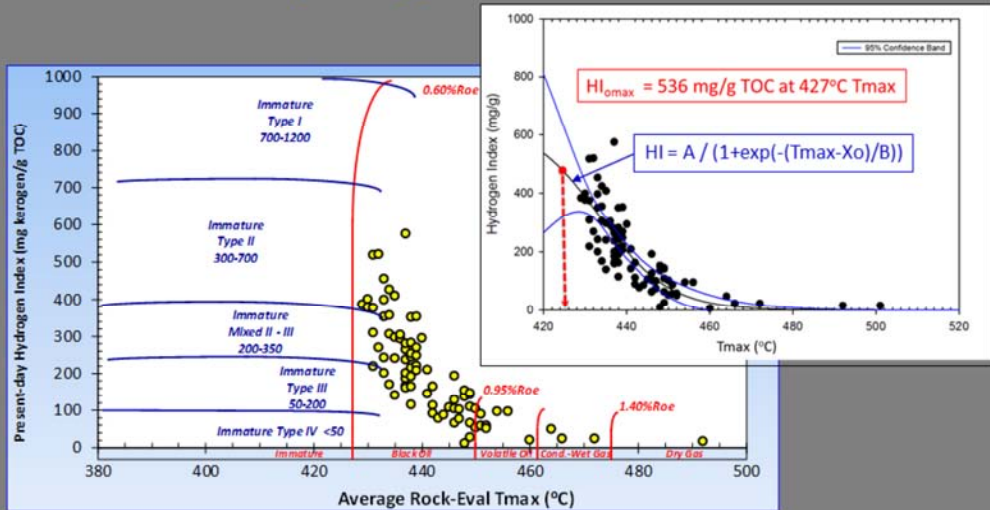
Carbonate vs.
Siliclastic
Marine Source
Rock Kinetics
modeled at
2°C/ma

at 0.80%Ro
carbonate is
78%
converted,
whereas shale
is only 62%
converted



Kinetics data from Pepper and Corvi, 1995. This shows the comparative difference in the extent of kerogen conversion at the same thermal maturity for a carbonate (very reactive) versus a less reactive shale both run at an arbitrary and constant heating rate of 2°C/ma – strictly for comparative purposes. Carbonates have more labile organic matter, both kerogen and the first generated petroleum (organic matter high in resins and asphaltenes).

Maturation Trend of Hydrogen Index vs Tmax



Allows prediction --->

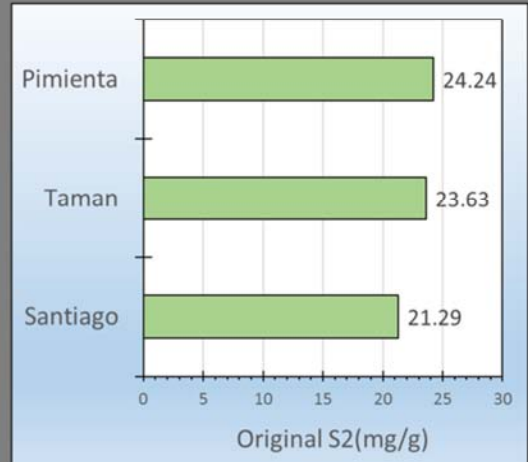
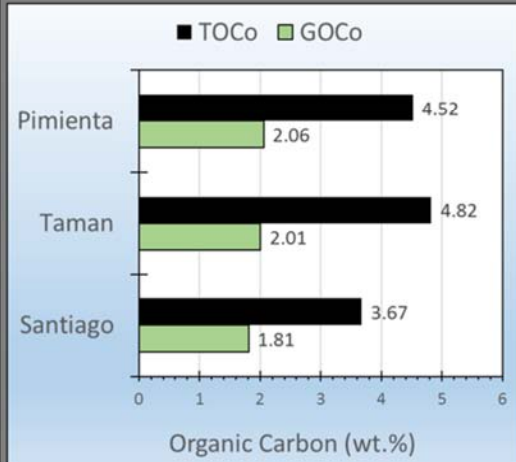
P90 HI_o = 394 mg/gT

P50 HI_o = 536 mg/gT

P10 HI_o = 602 mg/gT

Using average values for present-day HI values and Tmax, a decomposition trend(s) is obvious for the U. Jurassic in the Tampico-Mislanla Basin. These are calculated using a sigmoidal fit, providing an indication of the most likely original HI value as well as the lower and upper bounds. There is likely more than one trend indicated in these data, but the most typical (P50) value for the U. Jurassic Pimienta is an original HI of 536 mg/g TOC. A Tmax of 427°C is for the original value since the U. Jurassic is a carbonate source rock.

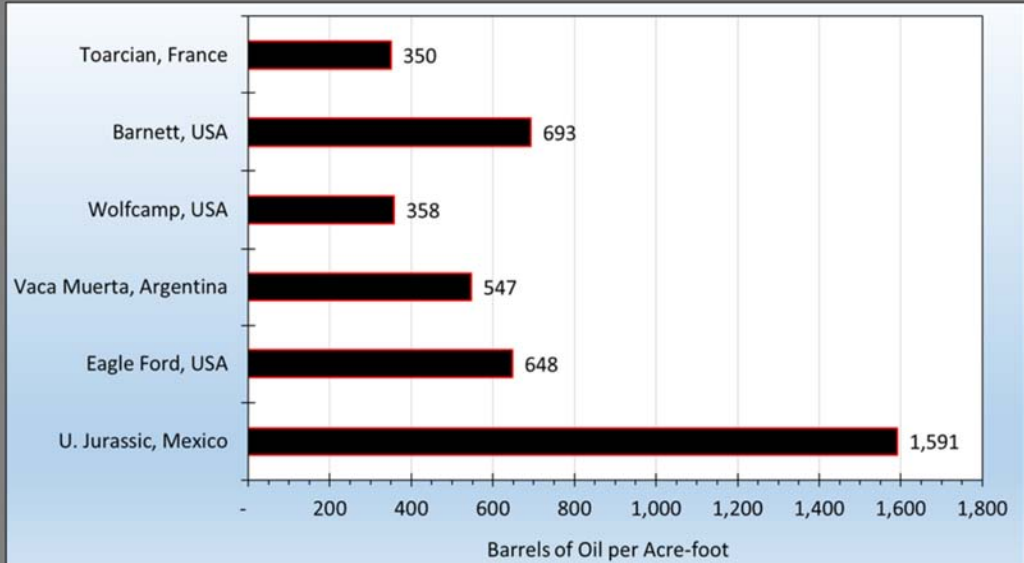
Restored Original Values based on averages



Original values are calculated based on the original HI value, showing the organic richness and generation potentials of the U. Jurassic intervals in the Tampico-Misantla Basin. The three units are highly similar in generation potentials, although organofacies differences are likely present.

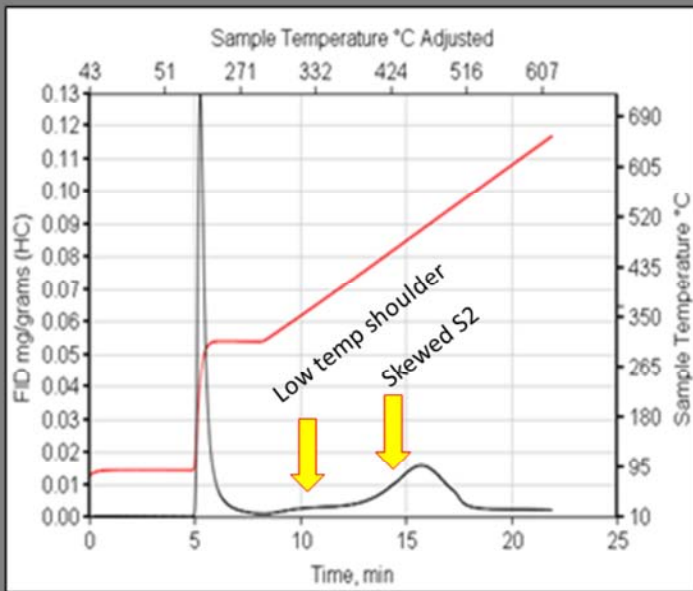
Comparison of Total Petroleum Generation Potentials

(does not account for thickness)



This is the total petroleum generation potential of each source rock. At a given thermal maturity, the yield will be lower. It is also important to understand that typically around 60% of generated petroleum is expelled, meaning ca. 40% retention. The retained petroleum is what might be recovered in an organic-rich source rock. In a hybrid system a portion of the expelled petroleum will be recovered. Retained petroleum is initially higher in resins and asphaltenes than expelled oil; cracking of these resins and asphaltenes proceeds along with kerogen cracking in the oil window.

Standard Bulk Thermal Extraction-Pyrolysis, i.e., Rock-Eval S1 and S2



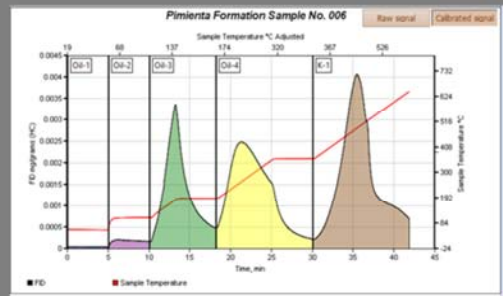
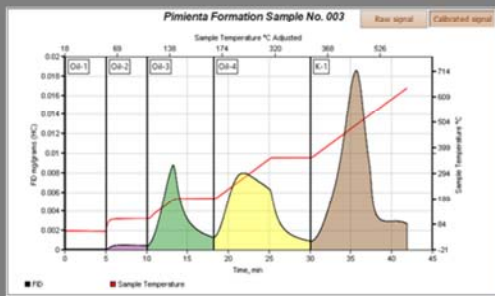
A typical source or reservoir rock may have petroleum that is eluted in Rock-Eval as S1, but also some petroleum will carry-over into the S2 peak along with kerogen. The low temperature shoulder skews the pyrolysis peak often, giving a lower Tmax by 4-8°C. The only way to determine the total petroleum in such a situation is to extract the rock and re-analyze in Rock-Eval. This does not account for evaporative loss of petroleum from S1, however. The total petroleum in a rock is

$$\text{Total Petroleum} = \text{S1} + (\text{S2}_{\text{whole rock}} - \text{S2}_{\text{extracted rock}}) + \text{estimated loss of S1 petroleum}$$

However, using advanced techniques in the HAWK pyrolysis instrument, the petroleum can be more accurately characterized.

HAWK Petroleum Assessment Method (PAM) of Pimienta Shale

- Estimate total, mobile, and immobile oil contents
- Predict physico-chemical properties: API gravity, viscosity
- Accurate kerogen yield and thermal maturity



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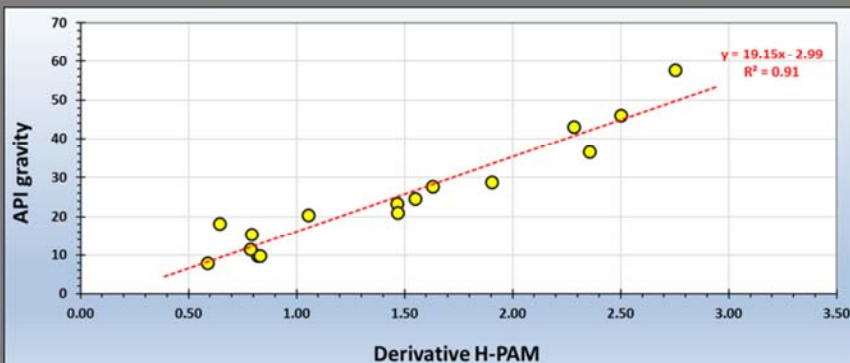
This shows a multiple soak and ramp program designed into the HAWK instrument for more accurate determination of petroleum content and its quality, along with more accurate determination of the kerogen content and its maturity from Tmax. This example shows the Pimienta Shale having significant amounts of higher molecular weight petroleum (note the high 'yellow' peak in Oil-4) indicative of lower API gravity. The clean kerogen peak gives an accurate kerogen yield for S2 and related HI values as well as an accurate Tmax value.

Multiple soak and ramp refers to various temperatures at which petroleum is eluted for a few minutes, and then subsequently raised to a higher temperature. This is repeated at multiple temperatures to separate various molecular weight ranges of petroleum.

Application of HAWK PAM Analysis

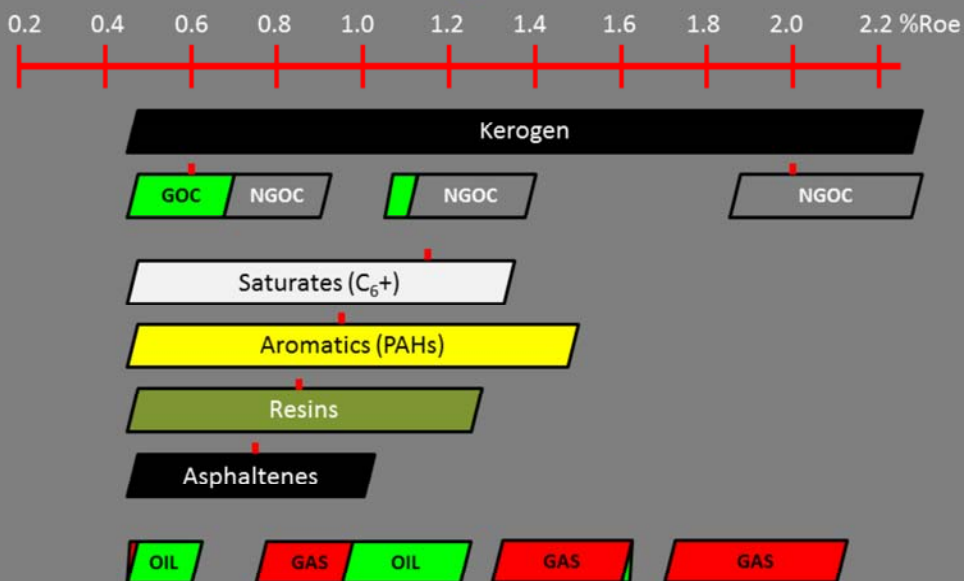
API Gravity Prediction on Pimienta Source Rock Samples

	Oil-1	Oil-2	Oil-3	Oil-4
Petroleum Fractions	C1-C5	C6-C7	C8-C14	C15-C40
	Saturates and Aromatics			Polars



Using the PAM analysis on HAWK (i.e., multiple ramp and soak program), API gravity can be predicted on reservoir rock samples, thereby providing an indication of the higher quality reservoir rock in terms of API gravity and related viscosity.

Principal (90%) “Life” Span: Retained Kerogen and SARA



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Jarvie, 2015

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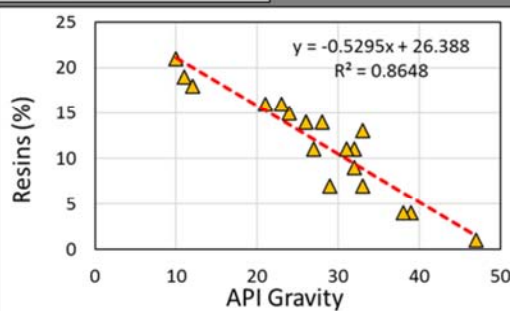
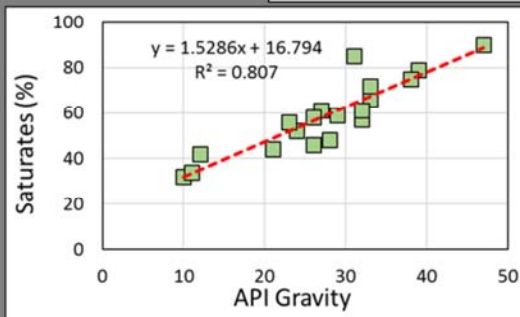
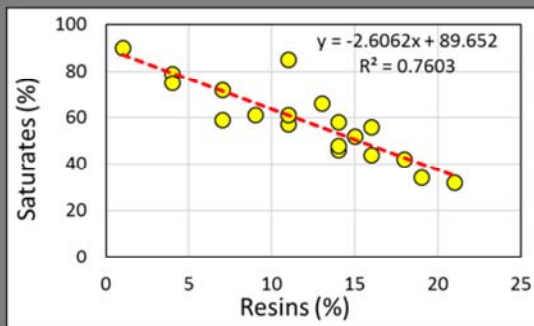
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Only a portion of the kerogen in a source decomposes to petroleum. This is referred to as the Generative Organic Carbon (GOC) (Jarvie, 2012). The remaining and generally the predominant portion is the Non-Generative Organic Carbon (NGOC). The difference is due to the hydrogen mass balance. Even the best Type II source rocks typically only have an atomic H/C ratio of 1.2, meaning there is insufficient hydrogen to saturate the organic carbon content.

Kerogen and secondary products (petroleum) decompose in the OIL WINDOW. The term ‘bitumen’ is often used for early products from kerogen, but in the strictest sense bitumen is petroleum. Petroleum or bitumen is comprised of saturated and aromatic hydrocarbons as well as the non-hydrocarbons, resins, and asphaltenes. Technically, hydrocarbons can only be carbon and hydrogen bearing compounds; thus resins and asphaltenes, having additional elements such as oxygen, sulfur, nitrogen, various metals, are non-hydrocarbons.

The earliest petroleum generated or bitumen contains more resins and asphaltenes and hence is lower quality in terms of API gravity and viscosity. However, asphaltenes and resins mostly decompose in the oil window as demonstrated by increasing oil quality with maturation. They are largely decomposed to saturates and a carbonaceous residue by about 1.2%Ro. Saturates and aromatics also crack to some extent in the late oil window forming C₂₀- condensates and certainly in the gas window.

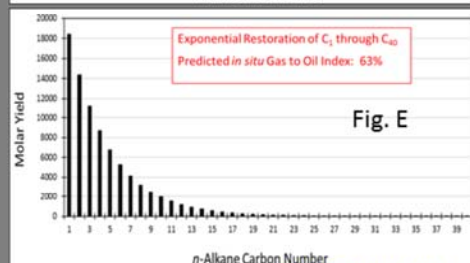
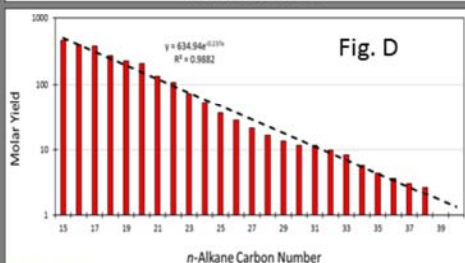
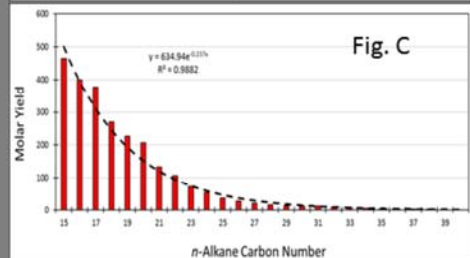
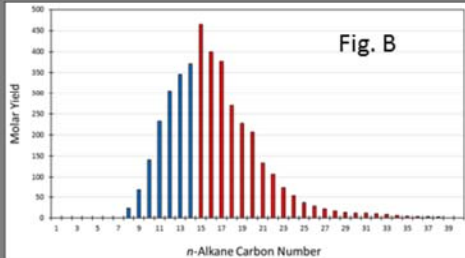
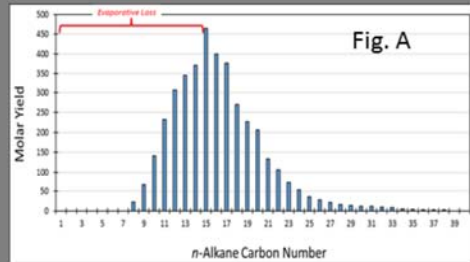
Saturates vs Resins, vs API Gravity



Data from Santamaria, 2000

These data support the inferences made on the previous slide. The upper figure shows that as resins decrease as a percentage of the total petroleum, saturated hydrocarbons increase. This also relates to API gravity: as the saturates increase API increases, and resins decrease.

Pimienta Oil Extract GC fingerprints



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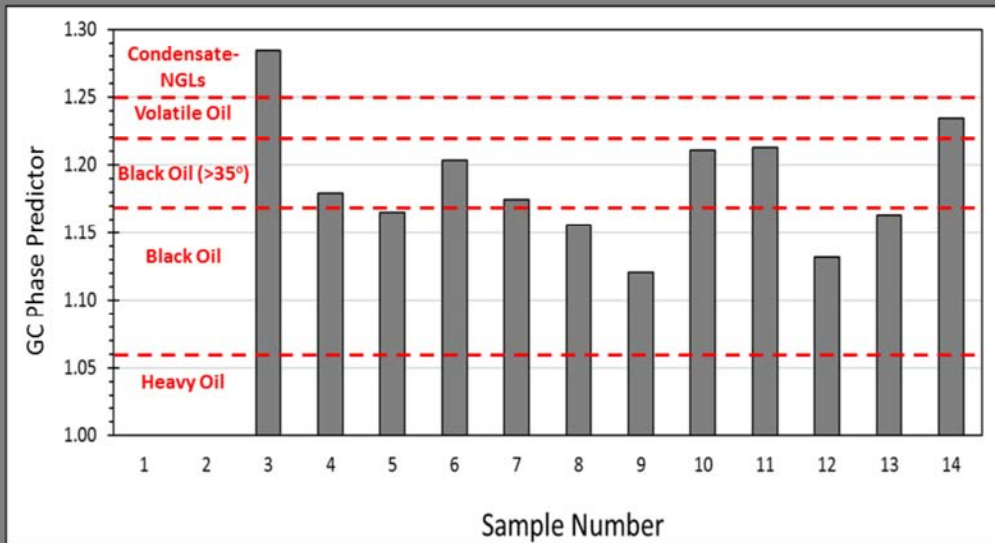
NAPO I.C. CARCUT 2010

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When oil is solvent extracted from a source rock, it often has lost many of the lightest hydrocarbons due to evaporation during drilling recovery, storage, and sample processing (Fig. A). Using the non-evaporated normal alkanes (shown as red bars in Fig. B), the molar yield of normal alkanes follows an exponential profile (Fig. C). The slope is easier to recognize when the molar yield is plotted on a logarithmic scale (Fig. D). The exponential fit of these data may then be used to extrapolate to C1 providing an indication of thermal maturity and the relative gas to oil index (GOI) (Fig. E). This is best utilized above 0.90%Ro, and alteration effects must also be considered such as gas exsolution, water washing, TSR, and BSR.

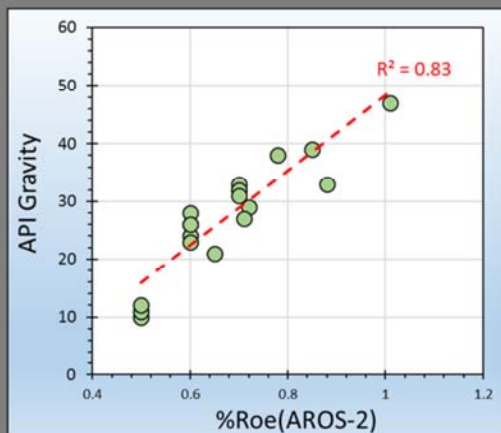
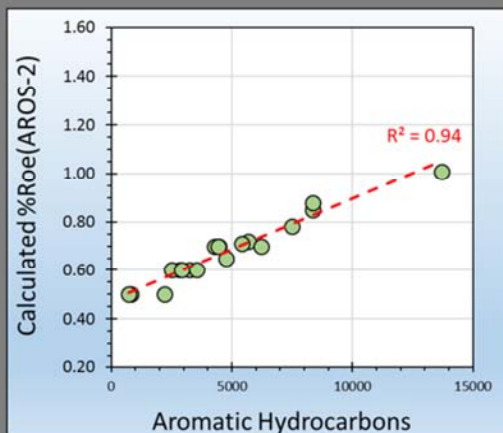
Product Type/Phase

Carbonate Organofacies



Using exponential fitting data we can estimate the oil type and quality.

New Maturity Technique: Quantitative aromatic hydrocarbons

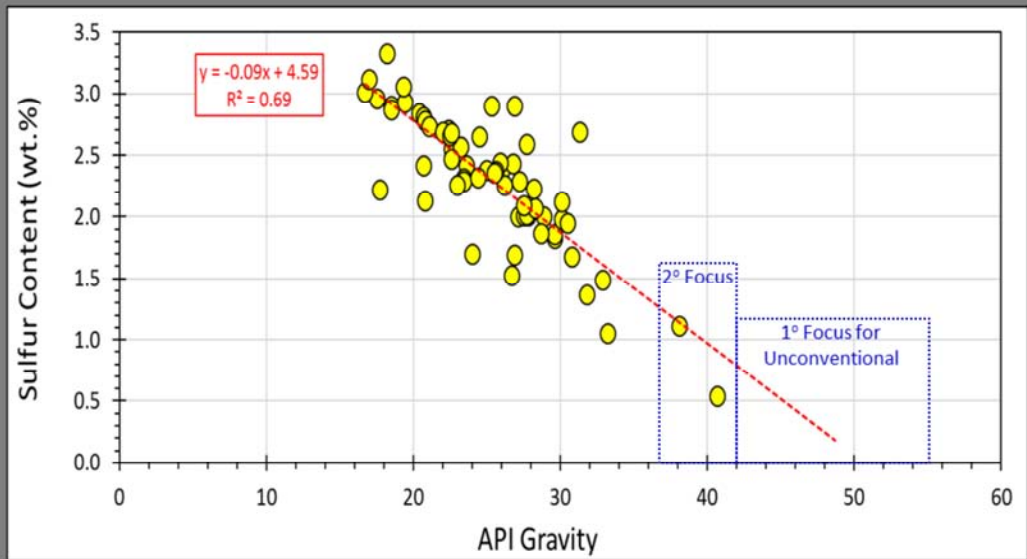


Data from Santamaria, 2000

Thermal maturity in marine shales is one of the more difficult analysis from which to obtain reliable results. Marine shales are typically low or devoid of land plant debris unless in a fluvial-deltaic setting, and thus, fossilized woody plant debris (i.e., vitrinite particles) are not likely present. Using various ratios of aromatic hydrocarbons that reflect their relative stabilities provides a means for obtaining quantitative thermal maturity data. In this case it is scaled to an equivalent vitrinite reflectance value, which is compared to API gravity of oils. This technique can be used on both oils and oils extracted from rock samples.

Sulfur in Generated Oils

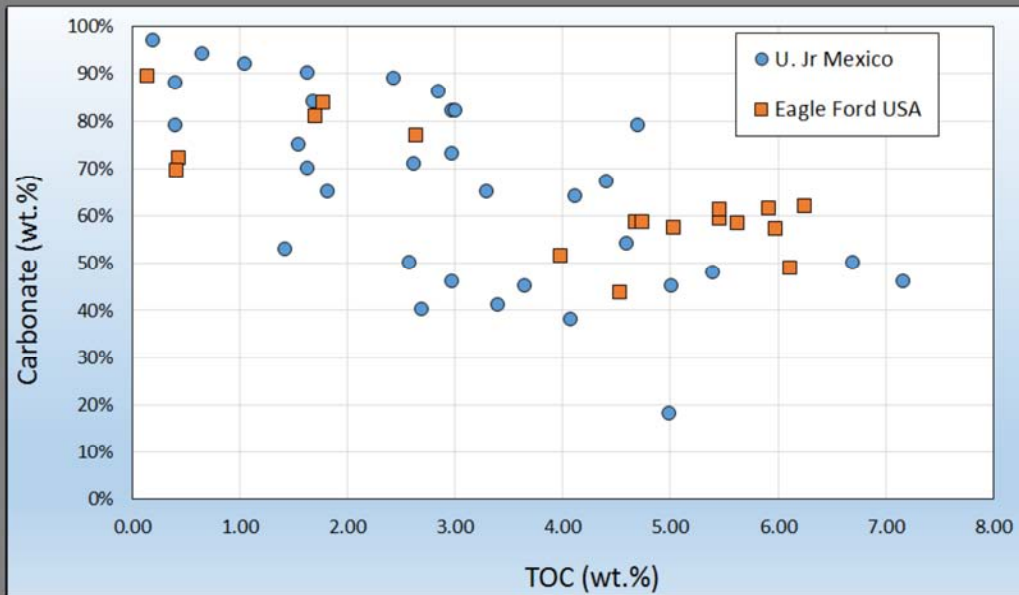
decreases with increasing thermal maturity



(conventional reservoir data from Morelos, 1996)

The U. Jurassic in the Tampico-Misantla Basin is known to have considerable sulfur content. However, this yield decreases with increasing thermal maturity and the focus on high-quality oil from tight oil reservoirs becomes very important.

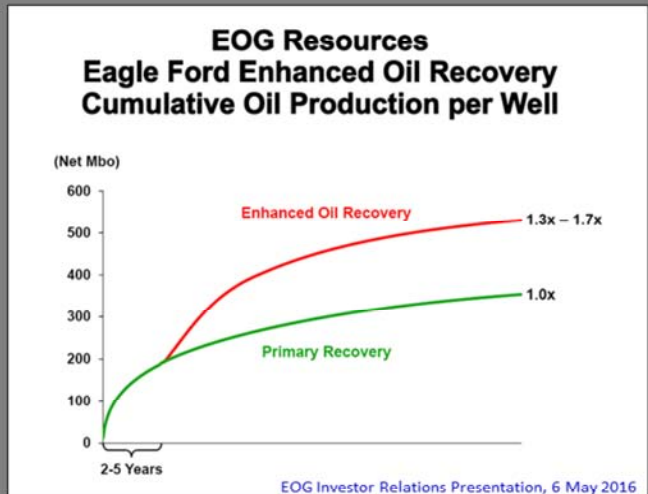
Carbonate Content relative to Organic Carbon Content



A comparison of the U. Jurassic carbonate content in the Tampico-Misantla Basin is comparable to that of the Eagle Ford Shale in South Texas.

U. Jurassic Shales, Tampico-Misantla Basin, Mexico: Potential for EOR

Characteristics suggested for Enhanced Oil Recovery in Eagle Ford are similar to Mexico's U. Jurassic, thereby further elevating unconventional production potential in Mexico



EOG Resources presented a generalized graphic of their enhanced oil recovery efforts in the Eagle Ford Shale, as referenced above. They did cite various limitations of such work, including the need to be able to isolate a given interval. A description of the EOR injection material was not described, but previous references were to gas injection. This could potentially reduce flaring if the gas is derived from the formation being treated for EOR. Their results suggest 30-70% increased recovery from the Eagle Ford.

Synopsis

- Onshore Tampico-Misantla Basin, Mexico contains U. Jurassic source rocks with the 'right' properties for excellent shale and shale hybrid resource potential:
 - High amounts of generated and retained or juxtaposed petroleum
 - At the appropriate maturities:
 - >40 API
 - > 1000 GOR
 - low sulfur
 - Brittle rock fabric based on ca. 52% carbonate content
 - Hybrid variations in rock fabric
 - Excellent potential for additional recovery via EOR

The Onshore Tampico-Misantla Basin, Mexico, has very favorable characteristics for unconventional shale development. It has characteristics comparable to the Eagle Ford Shale of south Texas. It will have oil in open fracture networks, tight shale, and tight juxtaposed, organic-lean lithofacies. Obviously this system has generated tremendous amounts of petroleum that will source conventional reservoirs which can be further developed as well.

Current Limitations to Production Success in Mexico's U. Jr Shale Resources

- Taxes/Royalties:
 - need to account for the high number of wells needed to develop unconventional shale resource plays as shown by Eagle Ford development (see page 5)
- Well costs:
 - critical mass yet to be achieved
- Price of oil

Various regions, basins, or countries have different services, taxes/royalties, infrastructure, and the like. Unconventional shale resource development is an expensive proposition and requires thousands of wells to fully develop. Favorable treatment for such development is extremely important to reach a critical mass on wells that have high service requirements for rapid drilling, water, proppants, and related services. While offshore wells may yield, e.g., 25,000 bbls of oil per day, a typical shale oil well might only yield 1,000 bbls/day, thus requiring 25 wells to reach the same level as a single offshore well. However, as shown in this presentation the resource potential is enormous, actually exceeding the potential for offshore... but requiring thousands of wells to achieve.

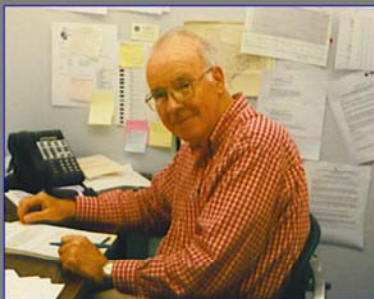
Well costs are a critical aspect of developing unconventional wells, and high volume and rapid service requirements must be in place to reduce such costs. Higher oil prices certainly help but does not change the need for critical mass of services.

Tribute to departed colleagues

Jack D. Burgess

AAPG Member for 60 years
Organic Petrologist

Microscopic examination of
kerogen (dispersed organic
Matter) in petroleum exploration
(1974)



Wallace (Wally) G. Dow

AAPG Member for 51 years
Organic Geochemist/Geologist

Most noted papers:

Petroleum Systems:
from source to trap (1995)



Jack Burgess worked with us for fifteen years at Humble Geochemical Services after retiring from Chevron in 1992. He retired at age 85. Jack was instrumental in our success with Mitchell Energy's exploration and ultimate development of the Barnett Shale in the Fort Worth Basin, Texas. My wearing a jacket and tie when outside the office evolved from Jack's old school approach which I admired. He was a tremendous individual to have the opportunity to work and learn from.

Wally Dow was my mentor in organic geochemistry. He was such a good teacher but only pointed me and made me earn the knowledge that I attained. Despite being occupied with running a business (DGSI) he took the time to direct my education in organic geochemistry. He is best known for being the father of the petroleum system approach which he and Jack Williams first used at Amoco in the 1970s as 'oil systems'. He is also well known for his maturity work and in particular his 1977 paper on petrology and its applications. We will all miss him dearly at AAPG and organic geochemistry meetings.

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*Viva
Unconventionals
in México !*



Thank you.

Questions or Comments?