Assessing Unconventional Resource Potential of Lower Cretaceous Carbonates in the South Florida Basin, USA*

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Search and Discovery Article #11071 (2018)**
Posted May 7, 2018

*Adapted from oral presentation given at 2017 AAPG Eastern Section 46th Annual Meeting, Morgantown, West Virginia, September 24-27, 2017

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Abstract

The South Florida Basin incorporates southernmost Florida, including the Keys and eastern Gulf of Mexico. It is a relatively simple southwest dipping structural basin with predominantly Cretaceous sediments. In this study, the two main unconventional exploration targets are the L. Sunniland Fm. and Pumpkin Bay Fm. The Sunniland is composed of mixed organic-rich/lean limestone and dolomites; shales are scarce to absent. Most conventional oil is found in carbonate reservoirs in the U. Sunniland and from fractured limestone in the LSRZ. The Pumpkin Bay is reported to contain organic-rich, argillaceous carbonates that are the likely source for oil in the mid/upper Pumpkin Bay and the brown dolomite zone of the overlying Lehigh Acres Fm.

An integrated investigation was conducted to assess hydrocarbon prospectivity of these L. Cretaceous source rocks, with a focus on the Collier Hogan 20-3 well. The L. Sunniland represents a moderate geochemical risk for shale oil development. It is a good source with zones of elevated organic richness (1.29 wt. % TOC) and dominantly oil-prone Type II-S kerogen. However, thermal maturity parameters indicate it is in the early oil window for Type II-S kerogen (0.56% Ro) and key risk ratios are below minimum thresholds for shale oil. Hydrocarbon yield calculations suggest the interval generated moderate amounts of oil and a majority of this has been retained within the source rocks. Core extracts and production oils are sulfur-rich (3.8 wt. %) and heavy (API 19.1°); characteristics associated with low maturity oil. Biomarker analyses clearly correlate produced oil with in-situ generation from the L. Sunniland. Although whole oil fingerprints showed abundant light hydrocarbons, bulk fractional

analysis show elevated polar+asph content (35%), suggesting the in-situ oils may be relatively immobile. The Pumpkin Bay was not extensively sampled, however, geochemical data suggest poor source potential (0.23 wt. % TOC) and a high risk for shale oil. Organic matter is composed of inert Type IV and gas-prone Type III kerogen. Thermal maturity parameters place the Pumpkin Bay in peak oil window (0.68% Ro) for Type II-S kerogen, but only incipient generation for a Type III kerogen. This amount of conversion would be sufficient to generate only trace amounts of hydrocarbons. Core extract biomarkers contain features associated with lean source rocks deposited under oxidizing conditions and clearly distinguish Pumpkin Bay from L. Sunniland samples.

Selected References

Feitz, R.P., 1976, Recent developments in Sunniland exploration of south Florida: Gulf Coast Assoc. Geol. Socs. Trans., v. 26, p. 74-78.

Jarvie, Daniel M., Ronald J. Hill, Tim E. Ruble, and Richard M. Pollastro, 2007, Unconventional shale-gas systems: The Mississippian Barnett Shale of north-central Texas as one model for thermogenic shale-gas assessment: AAPG Bulletin, v. 91, no. 4, p. 497.

Lewan, M.D., and T.E. Ruble, 2002, Comparison of petroleum generation kinetics by isothermal hydrous and nonisothermal open-system pyrolysis: Organic Geochemistry, v. 33, p. 1457-1475.

Palacas, J.G., D.E. Anders, and J.D. King, 1984, South Florida Basin - a prime example of carbonate source rocks of petroleum, *in* J.G. Palacas, ed., Petroleum Geochemistry and Source Rock Potential of Carbonate Rocks: AAPG Studies in Geology, v. 18, p. 71-96.

Pollastro, R.M., C.J. Schenk, and R.R Charpentier, 2001, Assessment of unconventional oil and gas in the onshore and state waters portion of the South Florida Basin, Florida - USGS Province 50, Chapter 1, National Assessment of Oil and Gas Project, Petroleum Systems and Assessment of the South Florida Basin: U.S. Geological Survey Digital Data Series DDS-69-A, Version 1.0, 70 p. Website accessed April 28, 2018.
http://pubs.usgs.gov/dds/dds-069/dds-069-a/REPORTS/SFB2000.pdf

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ASSESSING UNCONVENTIONAL RESOURCE POTENTIAL OF LOWER CRETACEOUS CARBONATES IN THE SOUTH FLORIDA BASIN, USA

Tim E. Ruble[1] and Stephanie Brightwell-Coats[2]

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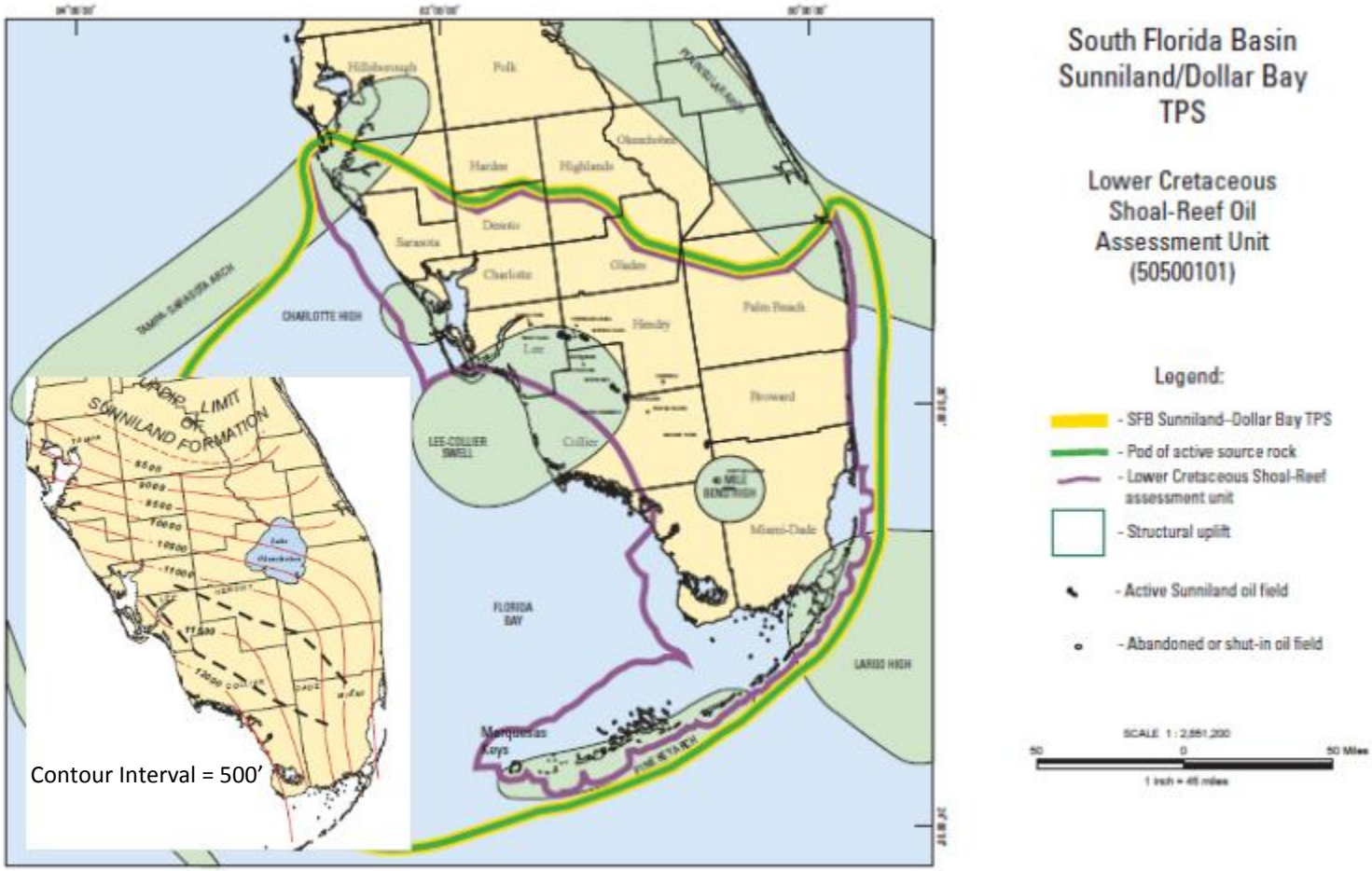
Base Map – South Florida Basin



Base map of showing the boundaries of the Sunniland/Dollar Bay total petroleum system as assessed by the USGS (Pollastro et al., 2001). Inset map is a structural contour drawn on the top of the Sunniland Formation.

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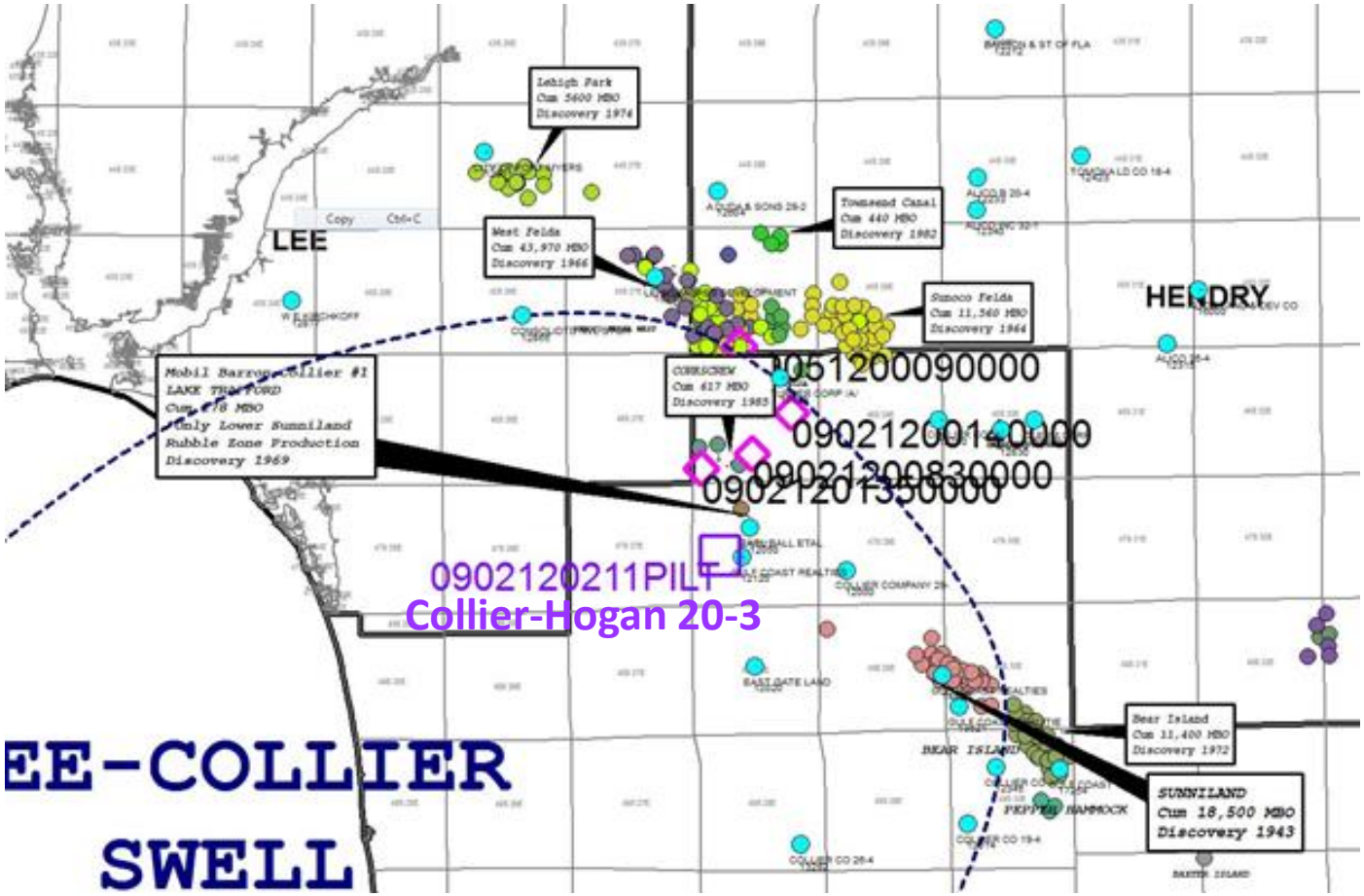
Enlarged Base Map – South Florida Basin



Enlarged base map illustrates the location of historic wellbores and significant conventional oil production data from the Sunniland Formation. The locations of five wells analyzed in the current investigation (client drilled core – purple rectangle; BEG core – pink diamonds) are also shown.

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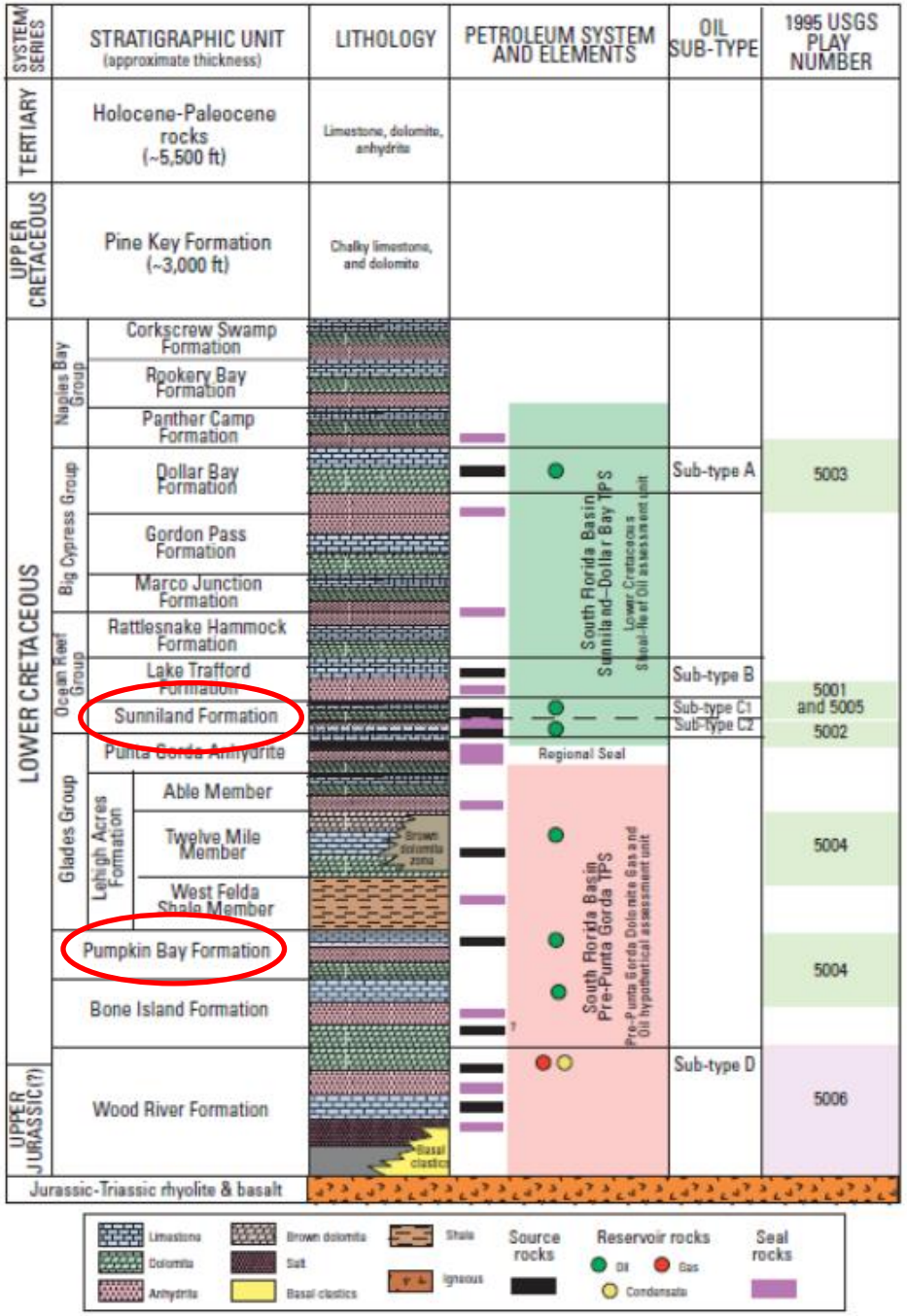
Stratigraphy

Stratigraphic section of South Florida Basin along Sunniland trend showing relation to petroleum-system elements including source rocks and seals (Pollastro et al., 2001).

Oil sub-types are also illustrated including those associated with the Upper Sunniland and Lower Sunniland (Sub-types C1 and C2, respectively).



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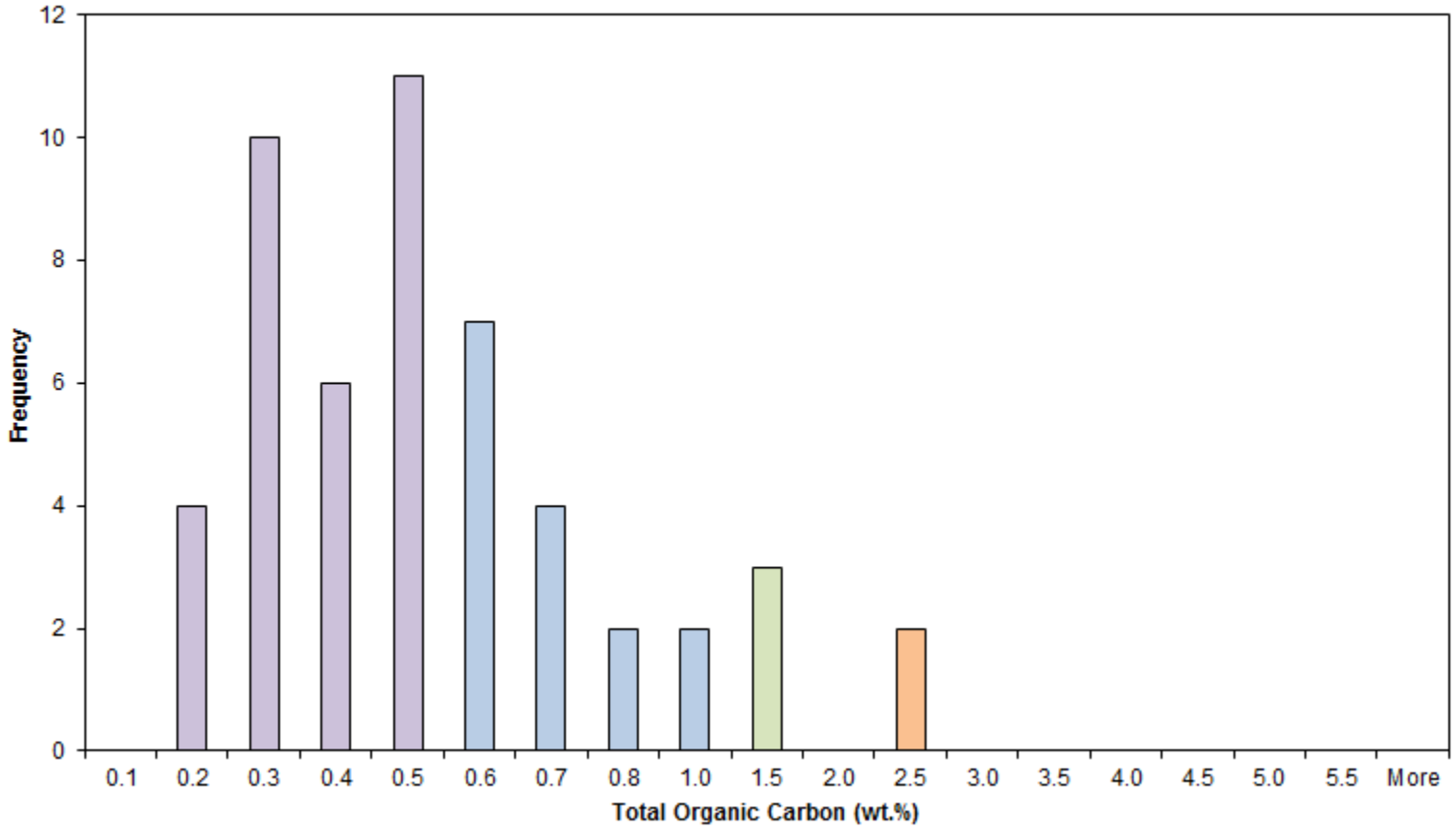
Sunniland & Punta Gorda TOC Distributions



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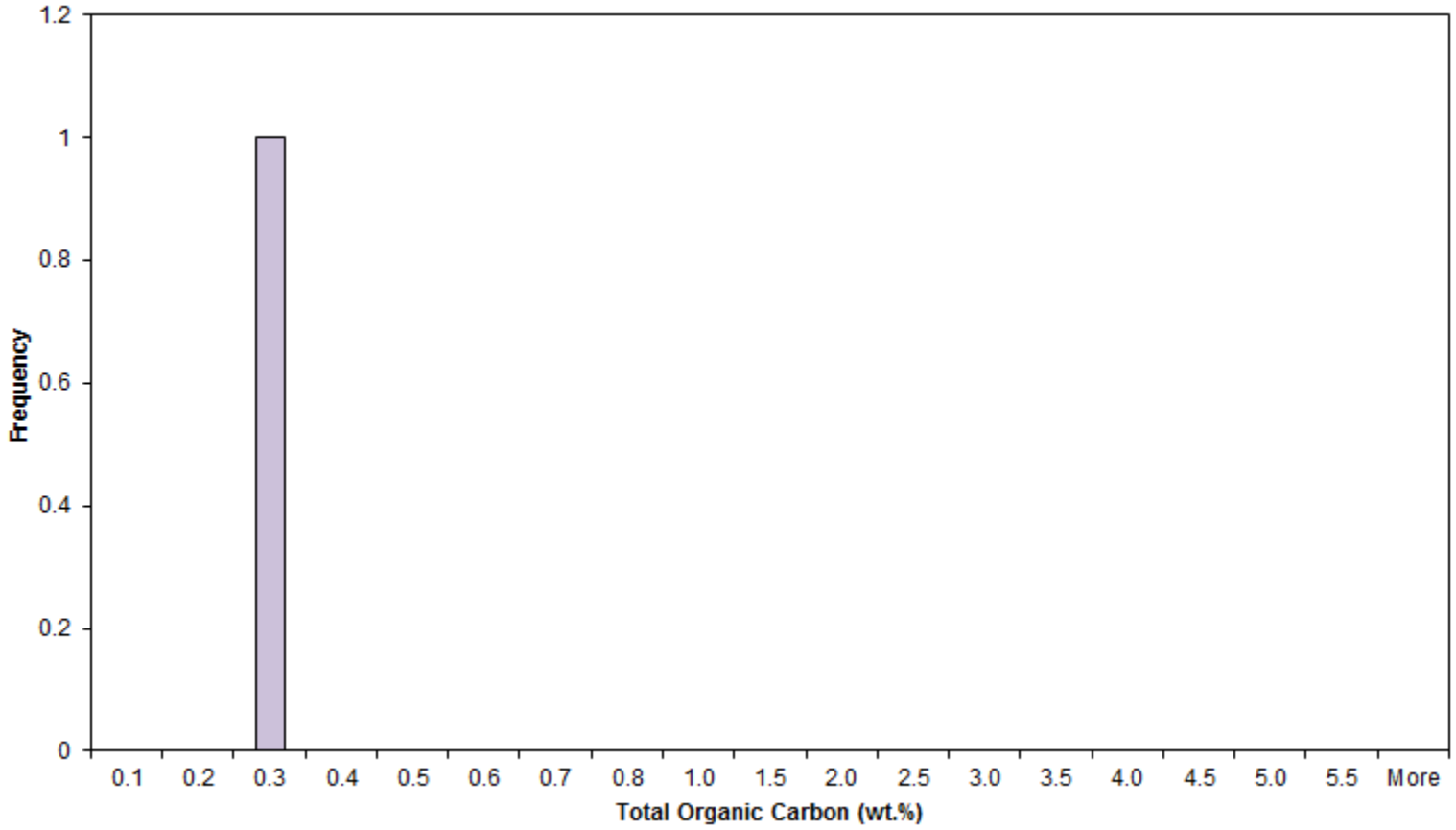
Pumpkin Bay TOC Distributions



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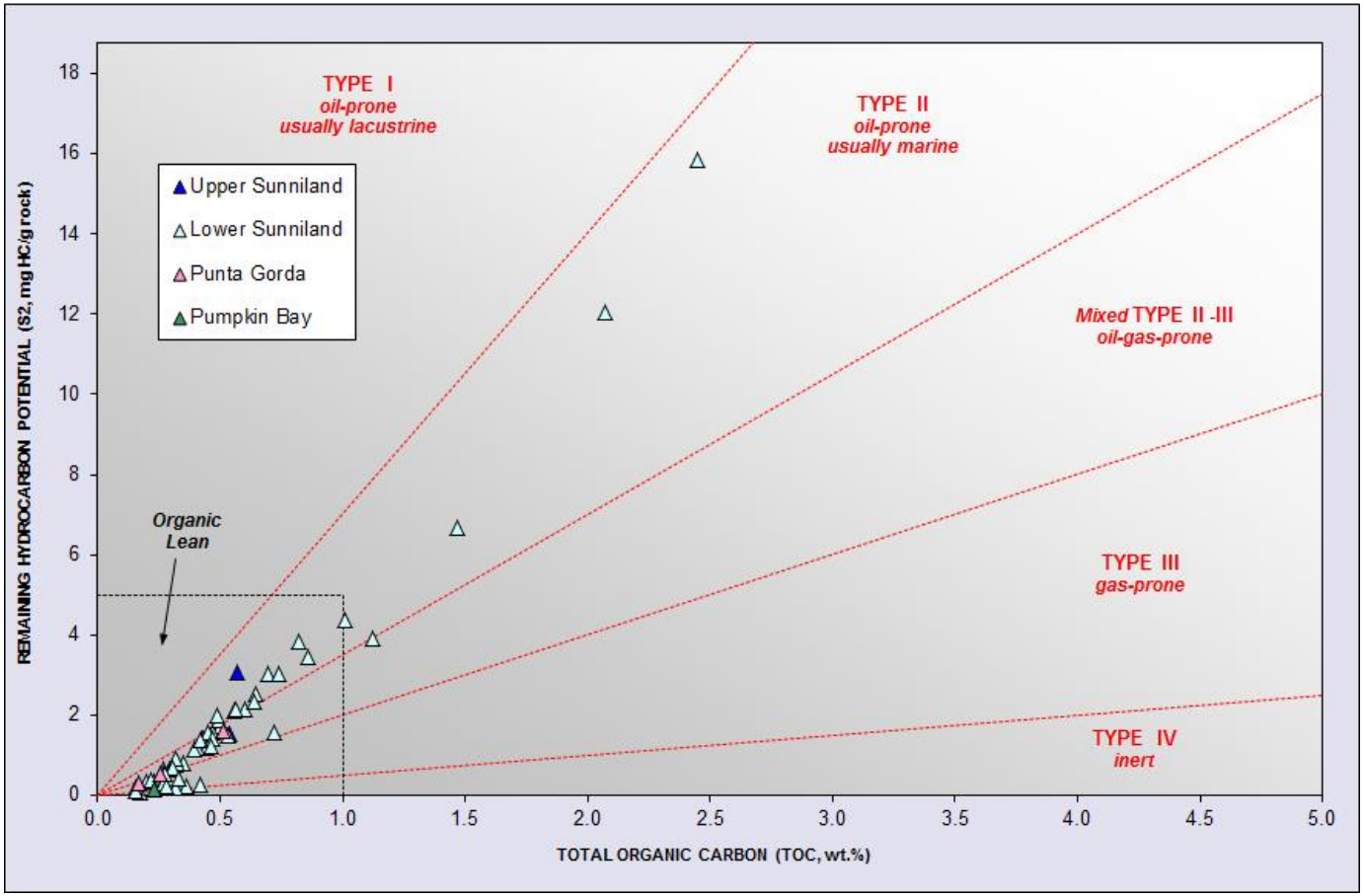
LOWER SUNNILAND Good TOC – Type II-S Kerogen

PUMPKIN BAY Poor TOC – Type III/IV Kerogen



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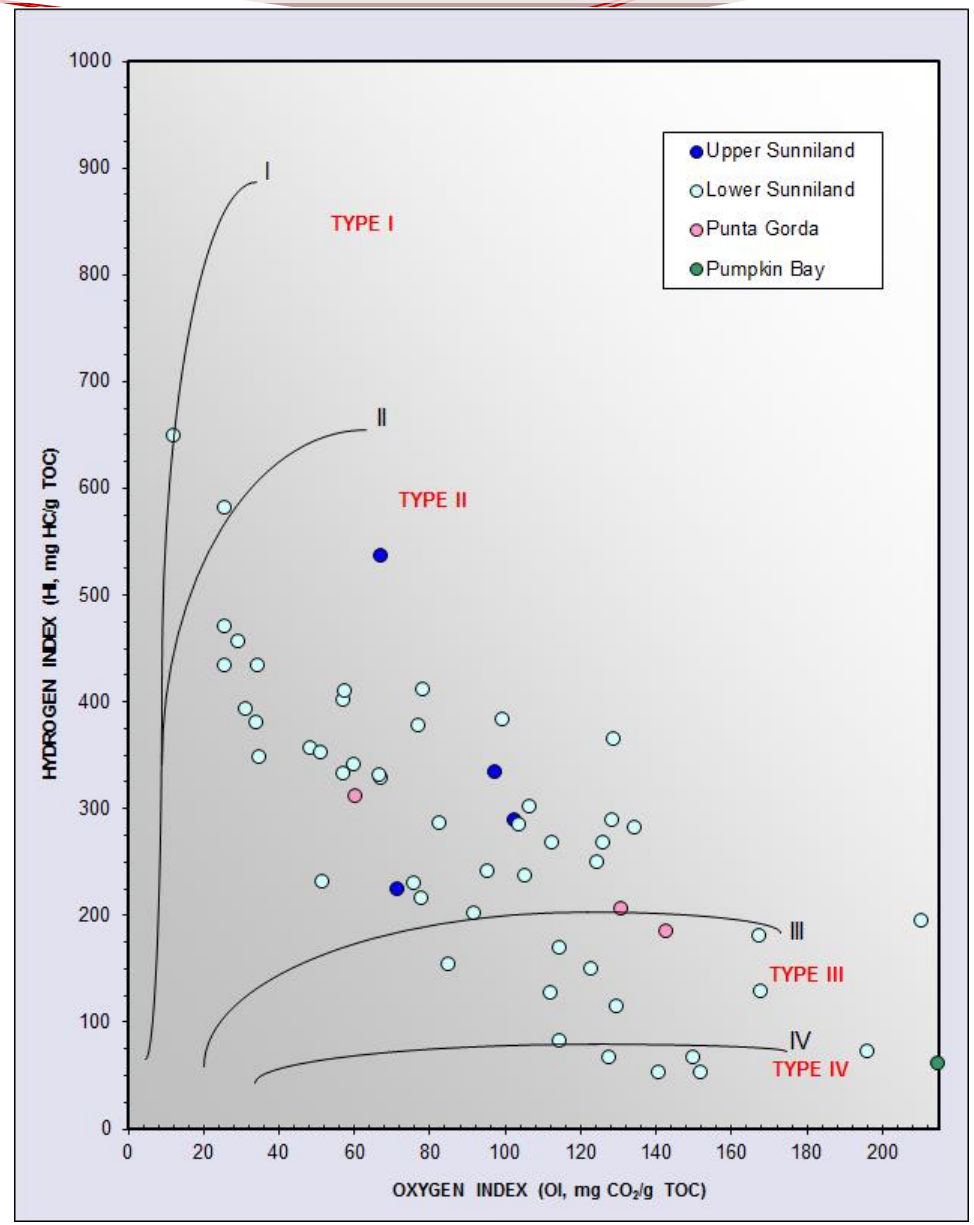
LOWER SUNNILAND KEROGEN TYPE

Type I-S oil-prone
Type II-S oil-prone
Type II-S/IV oil-prone/inert

PUMPKIN BAY KEROGEN TYPE

Type III/IV gas-prone/inert



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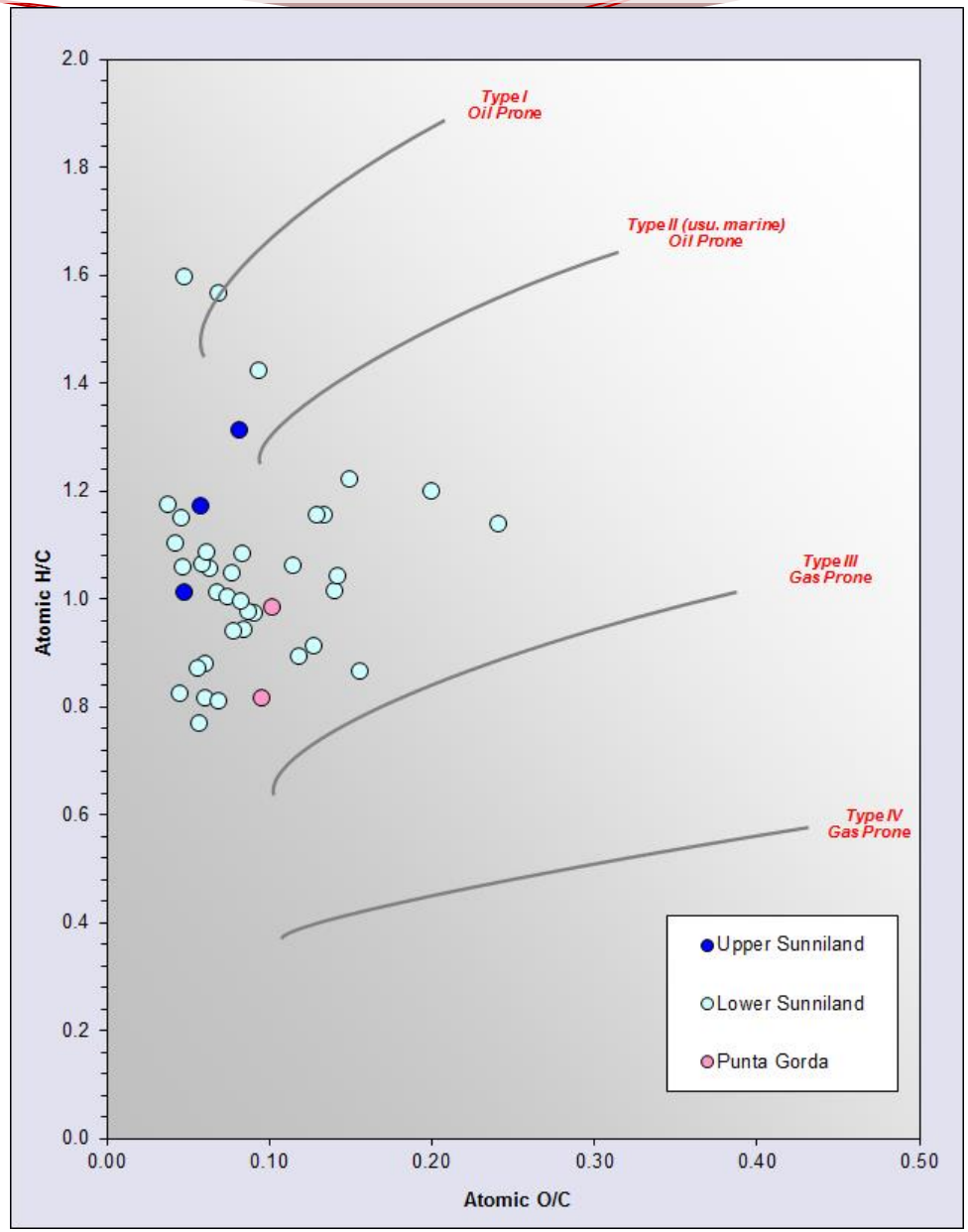
LOWER SUNNILAND KEROGEN TYPE

Type I-S oil-prone
Type II-S oil-prone
Type II-S/IV oil-prone/inert

Select samples based on available quantities



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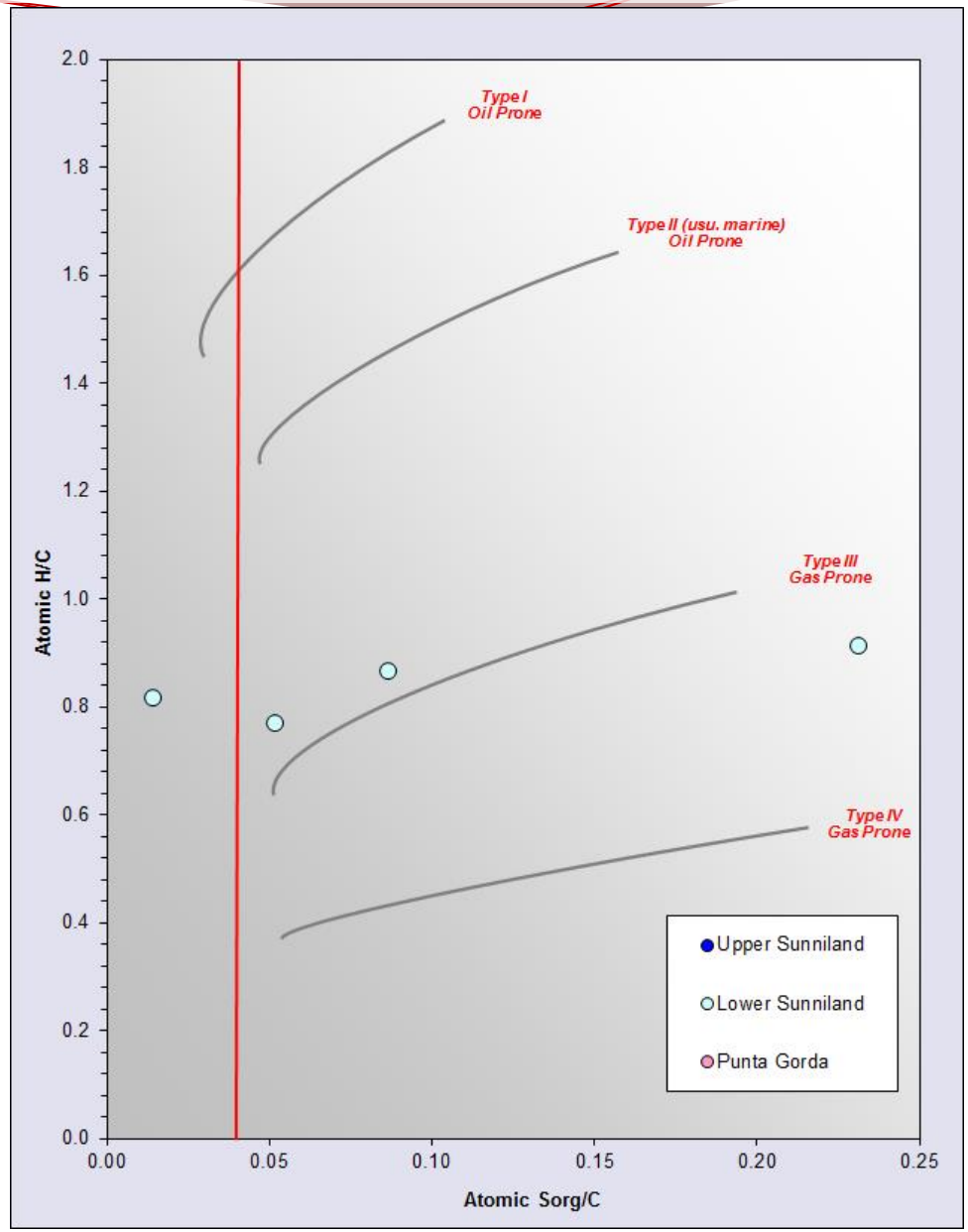
LOWER SUNNILAND KEROGEN TYPE

Type II-S/IV oil-prone/inert

Sorg/C > 0.04 — Type II-S

Select samples based on available quantities all have <0.5% TOC content



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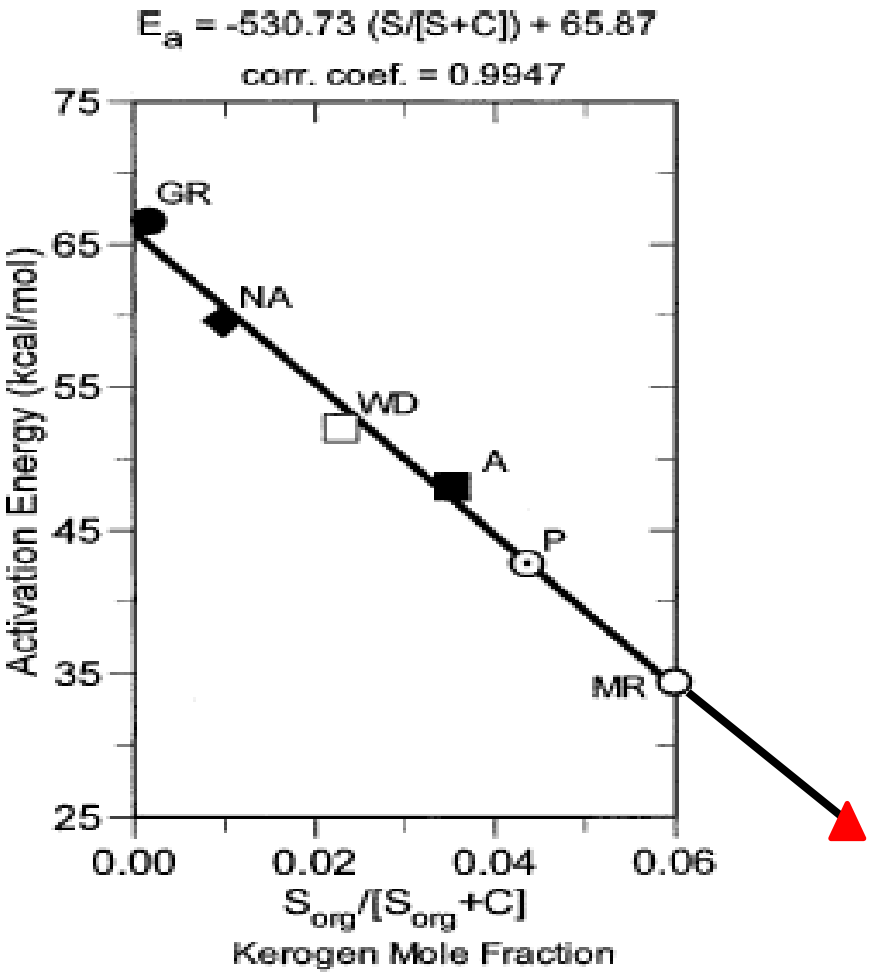
LOWER SUNNILAND KEROGEN TYPE

Type II-S oil-prone

Sorg/C = 0.08 (avg.)

Relationship between kinetic activation energy (Ea) and Sorg derived from hydrous pyrolysis. Sunniland (▲) would likely have even lower activation energies.



Monterey (MR), Phosphoria (P), Alum (A), Woodford (WD), New Albany (NA), Green River (GR) (Lewan and Ruble, 2002)

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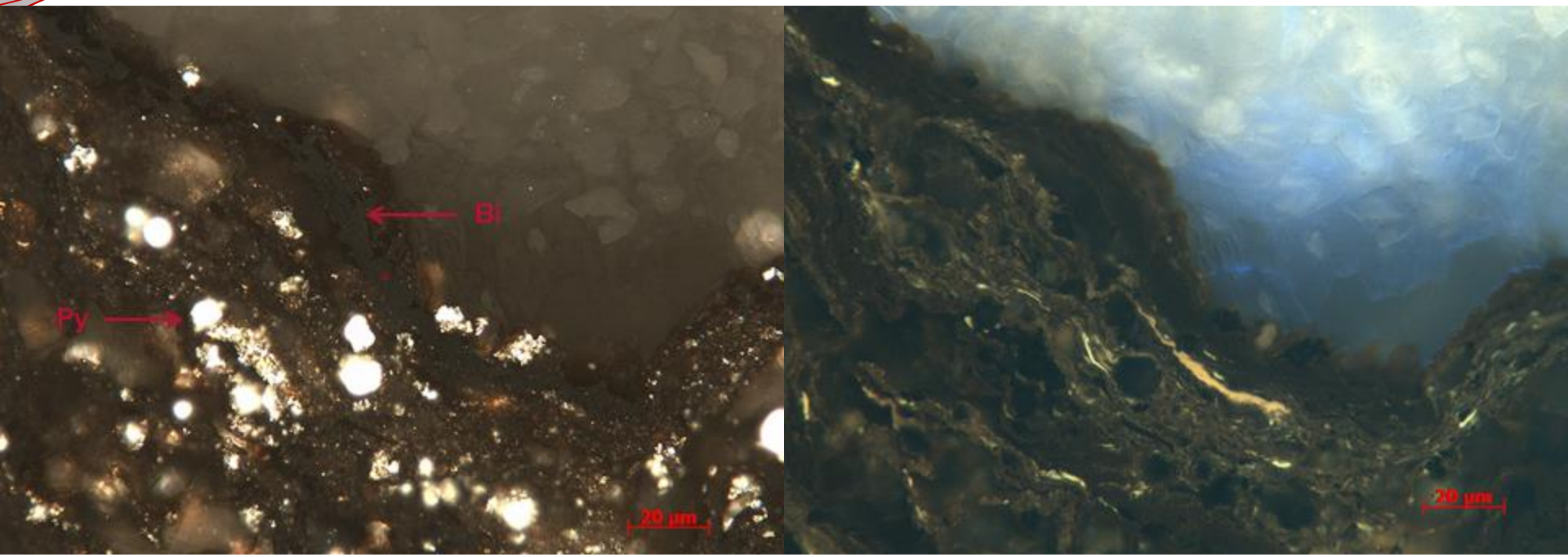
Collier Hogan 20-3



SUNNILAND KEROGEN TYPE

Photomicrographs from Sunniland in the Collier Hogan 20-3 well (11953.6'). Reflected white light image (left) shows mineral-organic matrix boundary with brownish lamalginite/AOM matrix (lower half of photo) including framboidal pyrite (Py) and thin bitumen lens (Bi). UV light (right) revealing common yellow to yellow/orange fluorescing filamentous algae typical of marine Type II-S kerogen and thin lenses of bitumen with weak brown fluorescence.

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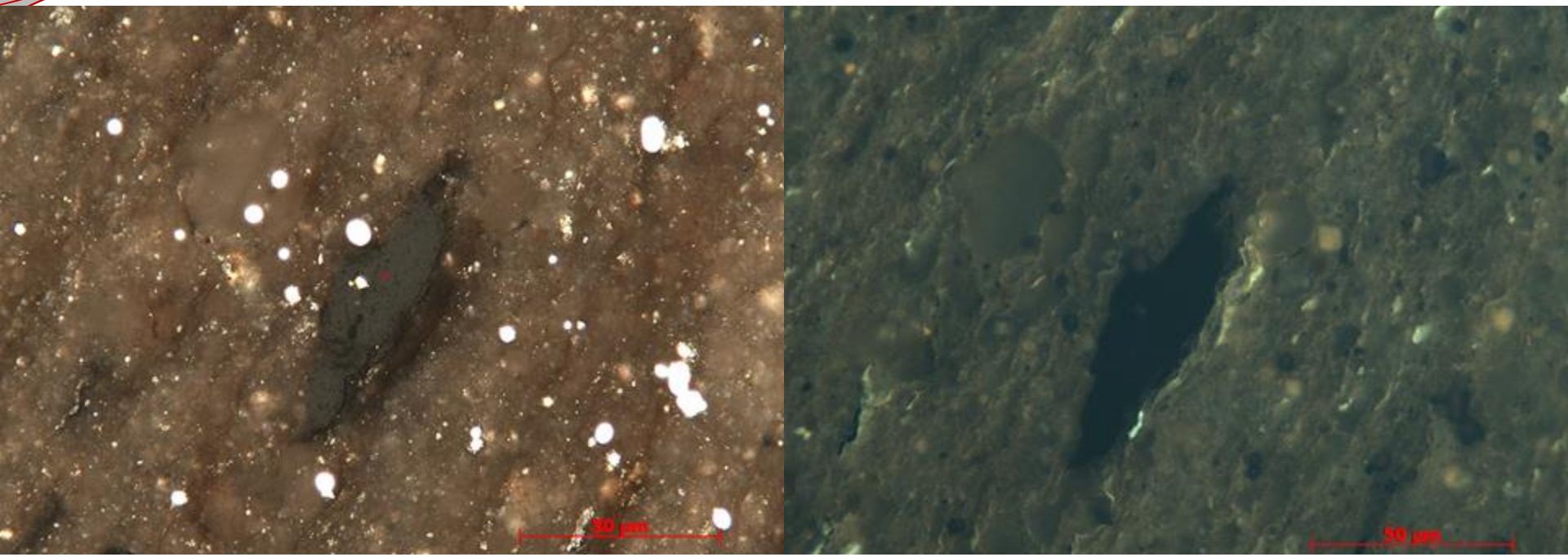
Collier Hogan 20-3



SUNNILAND KEROGEN TYPE & MATURITY

Photomicrographs from Sunniland in the Collier Hogan 20-3 well (11913.6'). Reflected white light image (left) shows representative vitrinite particle with reflectance of 0.54% R_o from the central measuring circle. UV light (right) revealing common yellow to yellow/orange fluorescing filamentous algae. The yellow fluorescence color suggests a maturity estimate of 0.40-0.65% VR/e.

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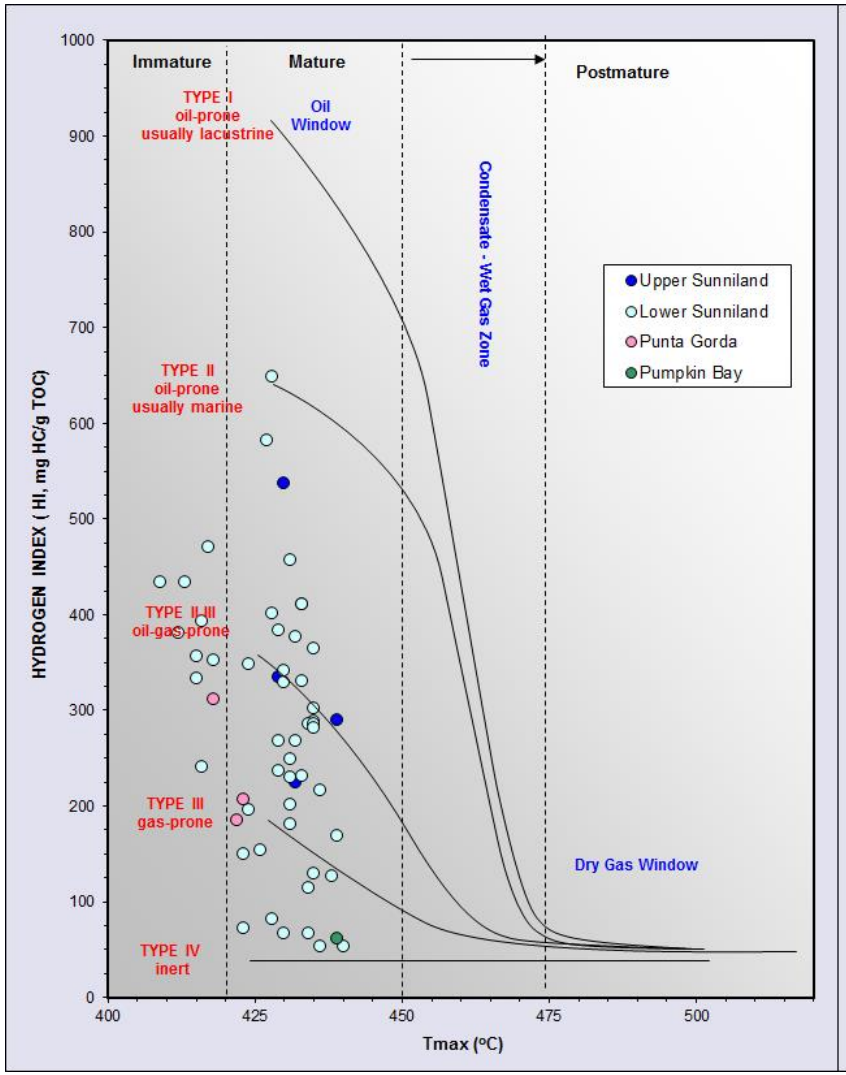
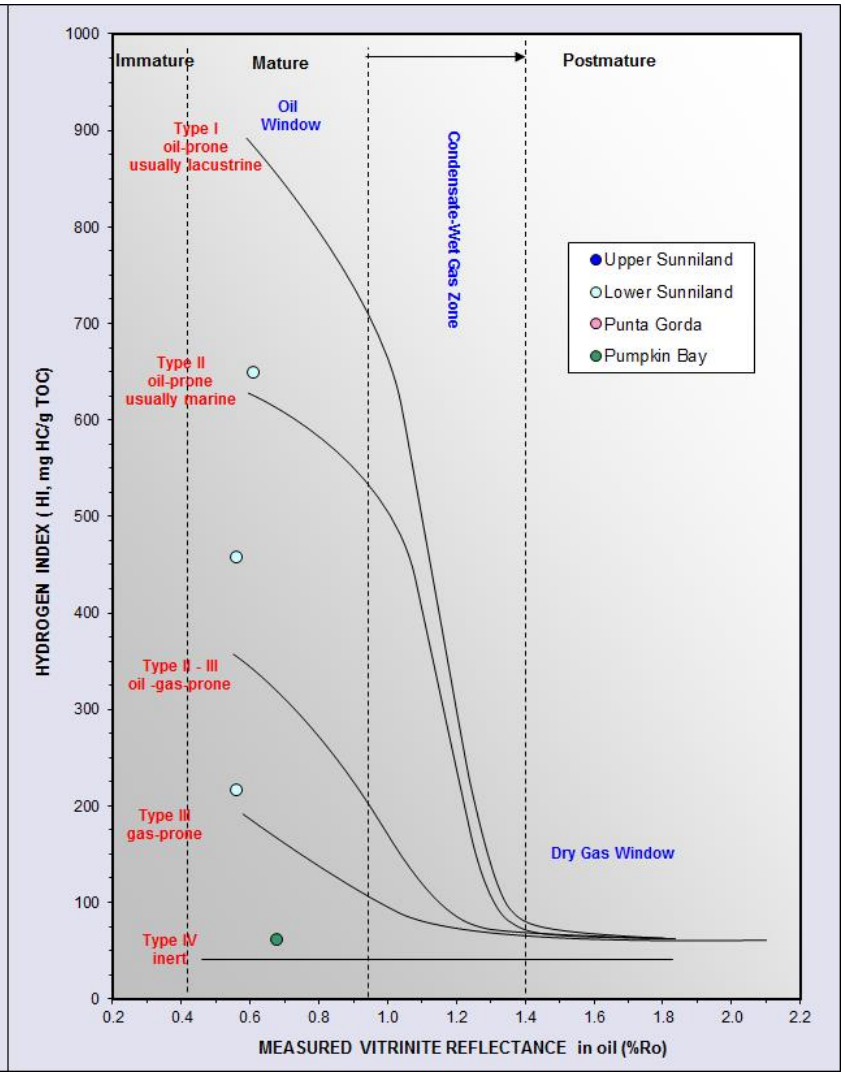
SUNNILAND & PUMPKIN BAY MATURITY Early Oil Window





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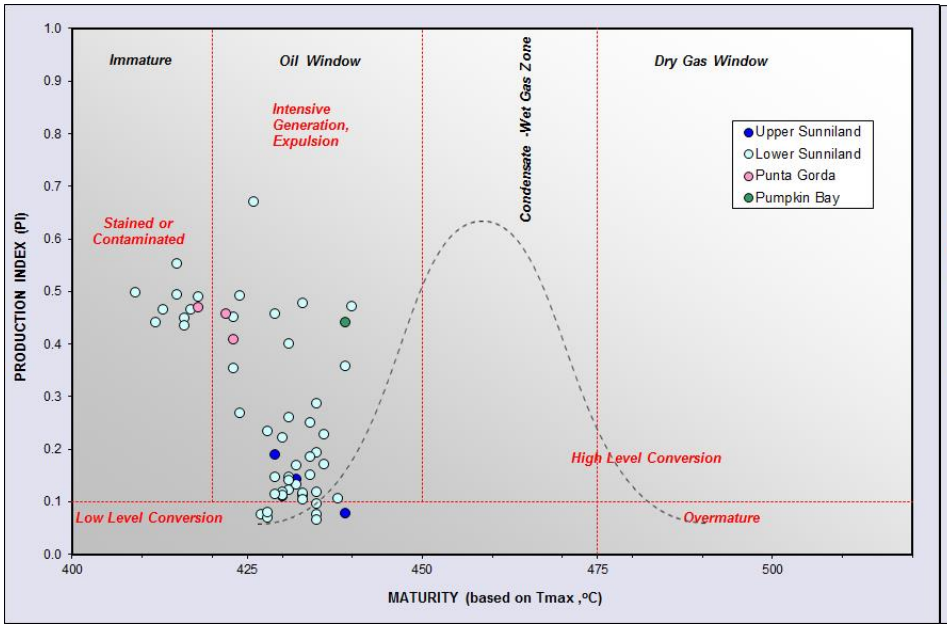
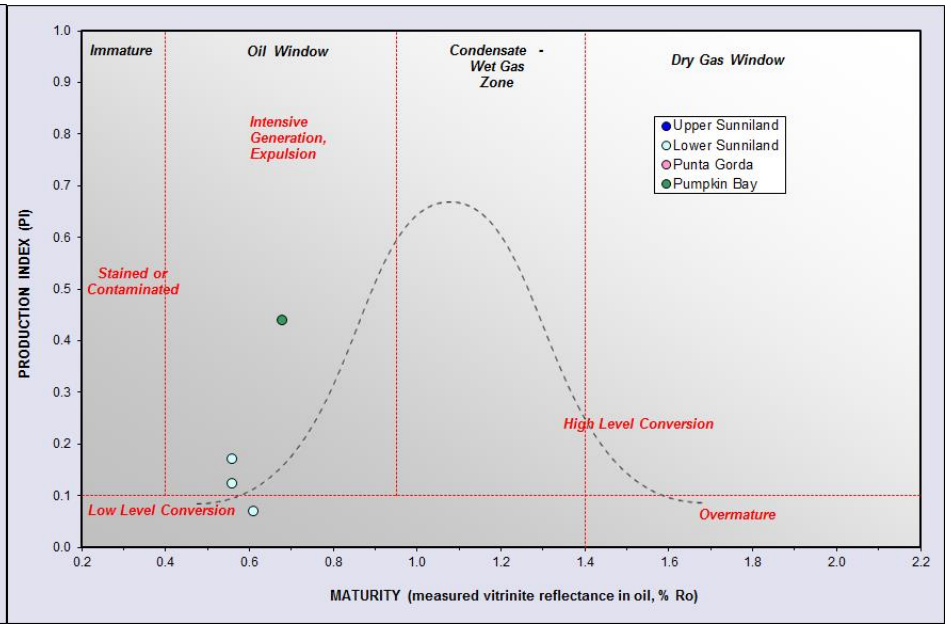
SUNNILAND & PUMPKIN BAY MATURITY Early Oil Window





SUNNILAND MIGRABITUMEN

Elevated PI & NOC values in some Sunniland samples could be due to the presence of migrabitumen within mineral grains and microfractures.

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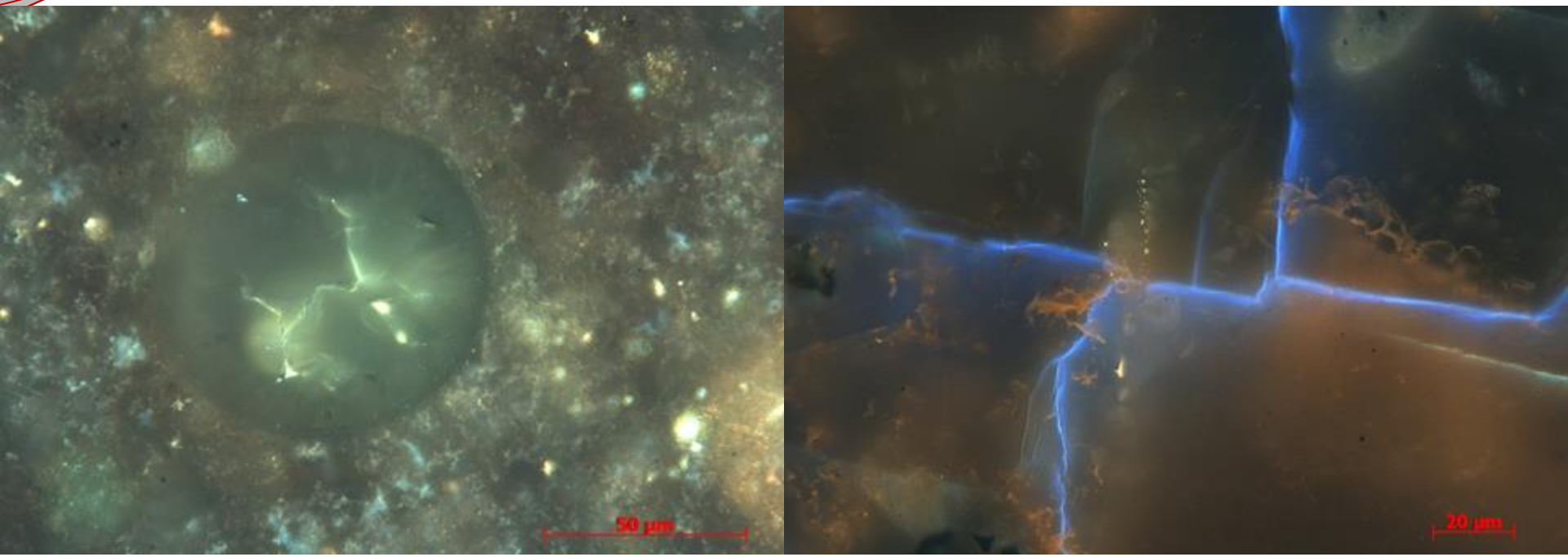
Collier Hogan 20-3



SUNNILAND MIGRABITUMEN

Photomicrographs from Sunniland in the Collier Hogan 20-3 well. Left photo shows rounded mineral grain with bright yellow fluorescing hydrocarbons trapped within microfractures. Right photo illustrates pinpoint yellow fluorescing fluid inclusions (center) and mineral fractures filled by blue thin section dye and orange fluorescing dead oil/bitumen. Elevated PI & NOC values could be due to presence of this migrabitumen.

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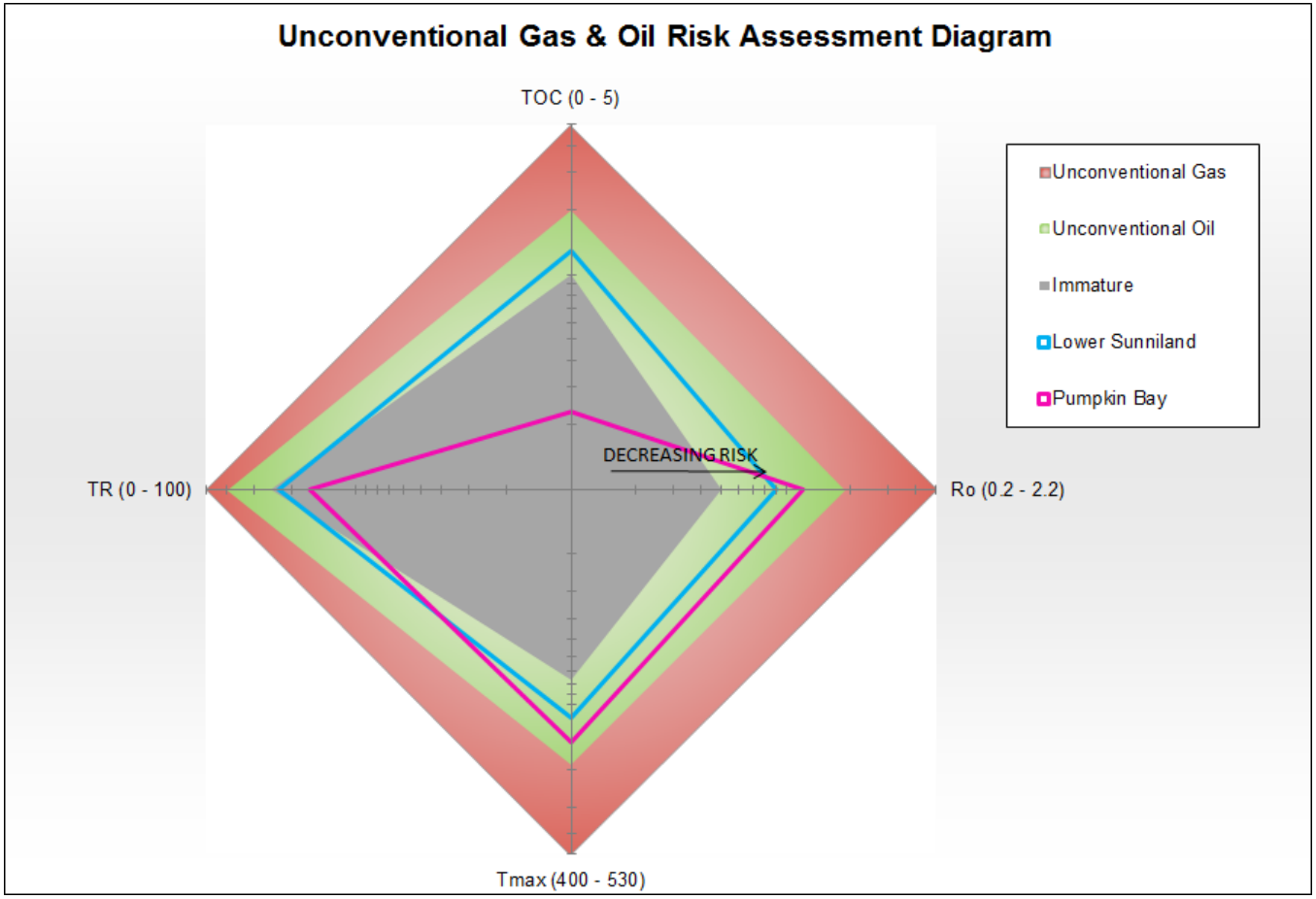
SOUTH FLORIDA BASIN RISK ASSESSMENT



LOWER SUNNILAND OIL – MODERATE RISK

PUMPKIN BAY OIL – HIGH RISK

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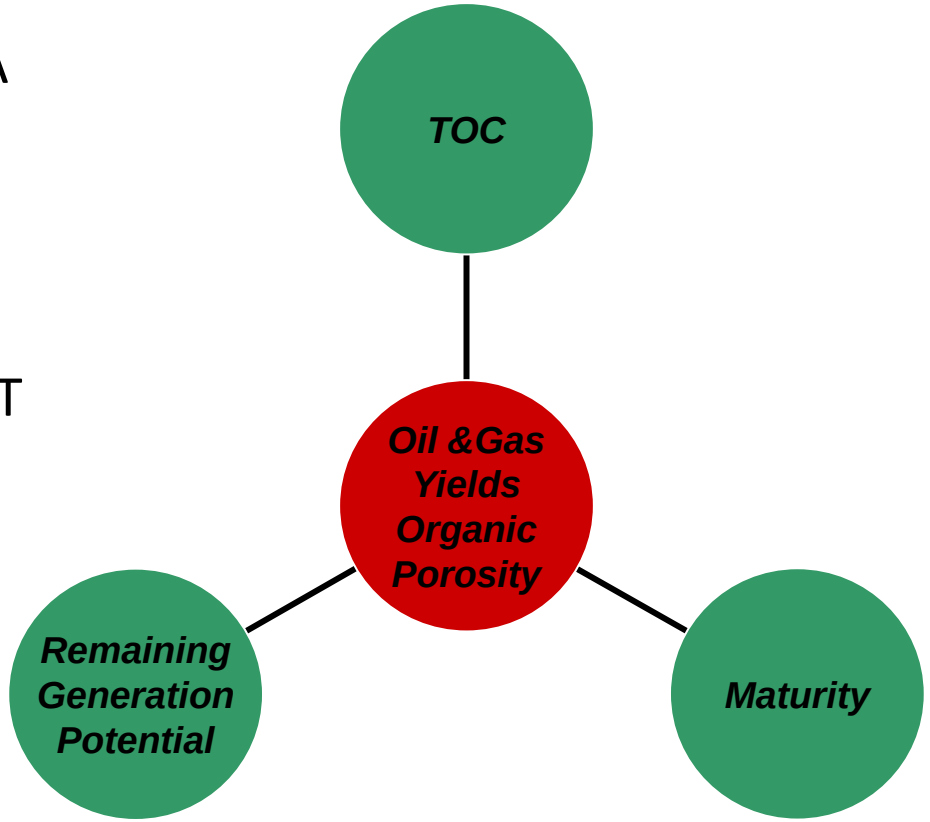
HYDROCARBON YIELDS

SHALE GEOCHEMICAL DATA
Source Rock Analyzer

+

GEOCHEMICAL ASSESSMENT
Evaluate & Plan



Jarvie et al. (2007) AAPG Bulletin, v. 91, no. 4, p. 497

Chen and Jian (2017) AAPG Bulletin, v. 100, no. 3, p. 405-422

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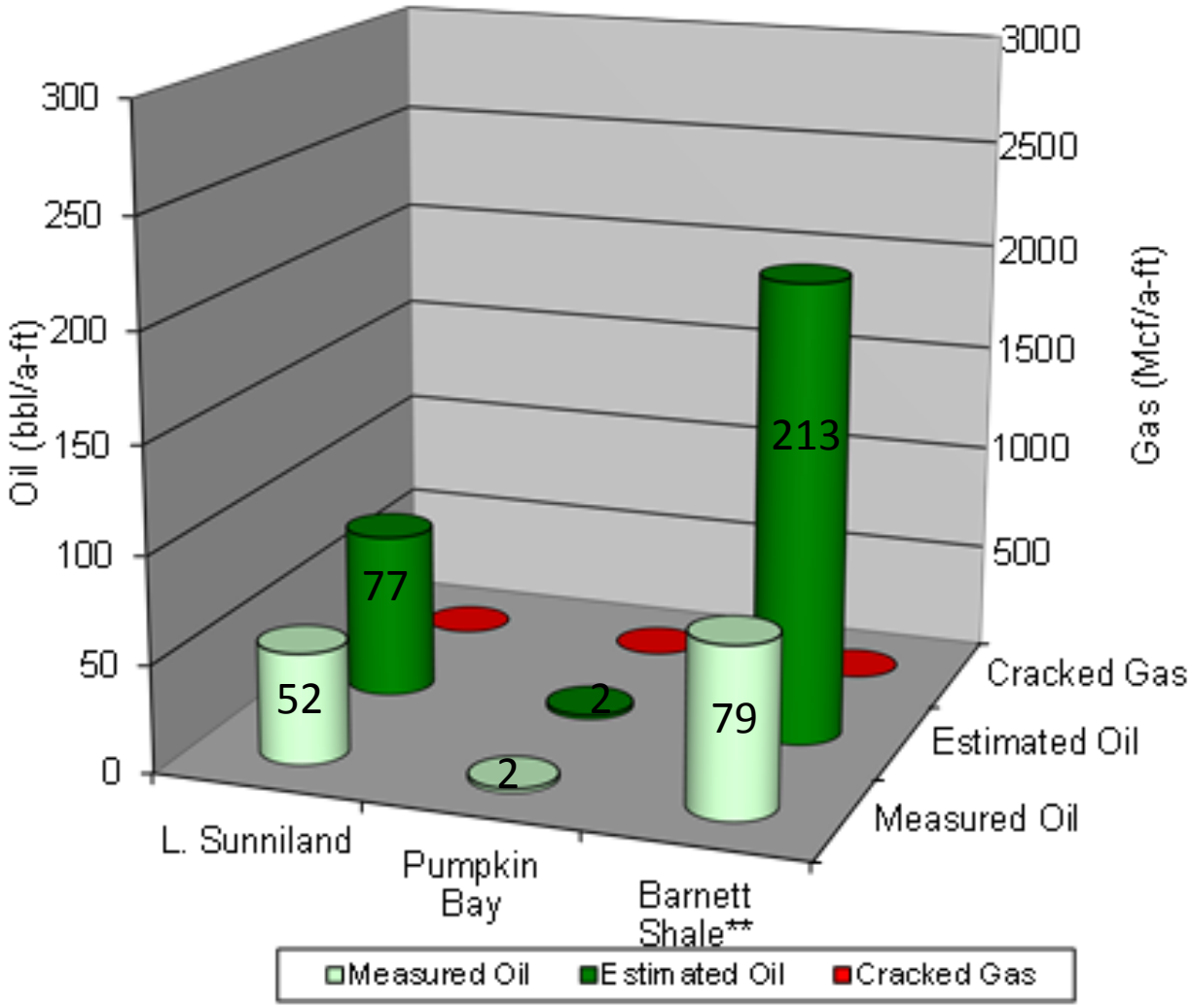
Collier Hogan 20-3 HYDROCARBON YIELDS



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Well	Sample Identifier	Sample Type	Formation	Sample Description
Collier Hogan 20-3 Pilot	S13203	Extract	Pumpkin Bay	Probable condensate when sampled off shakers; 13203' TVD
Collier Hogan 20-3 Pilot	S-R2/PG	Extract	LSRZ Lower Sunniland Rubble Zone	Contact with Punta Gorda just below lateral target; ~12200' TVD
Collier Hogan 20-3 Lateral	12910	Extract	LSRZ	12910' lateral shaker sample
Collier Hogan 20-3 Lateral	13400-13600	Extract	LSRZ	13400-13600' lateral shaker sample
Collier Hogan 20-3 Lateral	13600-14000	Extract	LSRZ	13600-14000' lateral shaker sample
Collier Hogan 20-3 Lateral	14087	Extract	LSRZ	14087' lateral shaker sample
Collier Hogan 20-3	Lemur	Oil	LSRZ	Produced oil from lateral
Gulf Coast Realties 23-A	Gulf Coast	Oil	Sunniland	WFT Labs Stock Production Oil

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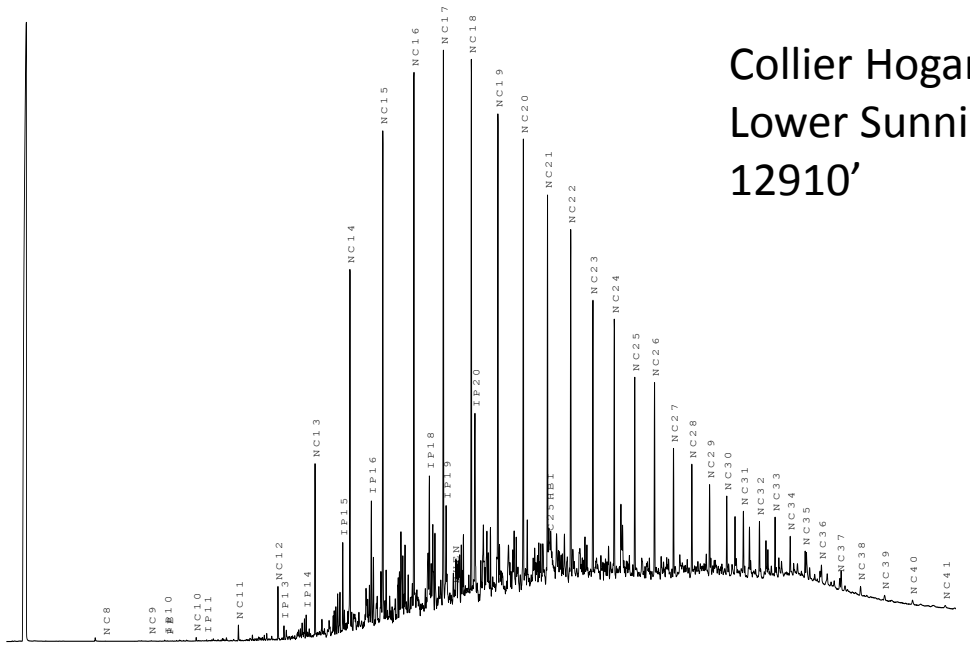
GC Fingerprint



Collier Hogan 20-3
Lower Sunniland
12910’

Extract gas chromatogram from L. Sunniland source rock sample in the Collier Hogan 20-3 well. Normal alkane envelope is unimodal with maxima in the C14–C17 range. Carbon Preference Index (CPI) values are in the 0.89 to 0.95 range, indicating an even carbon predominance that is fairly typical of marine carbonate source rocks.

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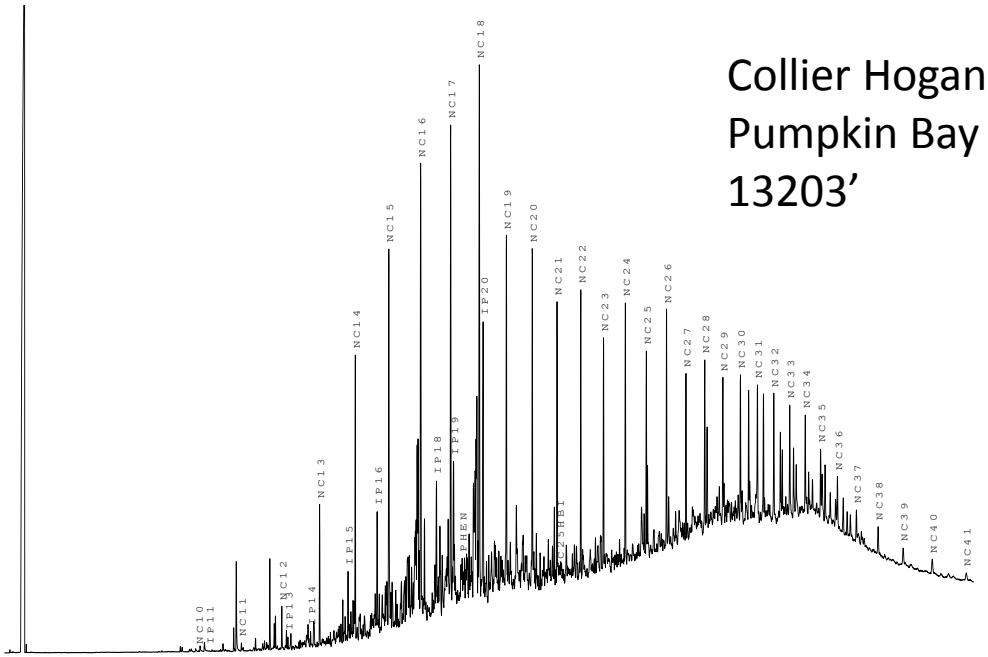
GC Fingerprint



Collier Hogan 20-3
Pumpkin Bay
13203’

Extract gas chromatogram from Pumpkin Bay source rock sample in the Collier Hogan 20-3 well. Normal alkane envelope is characterized by an unusual step-wise pattern that is also somewhat bimodal with a distinct maxima at C18 and at C26. The Carbon Preference Index (CPI) value of 0.90 indicates an even carbon predominance that is fairly typical of marine source rocks.

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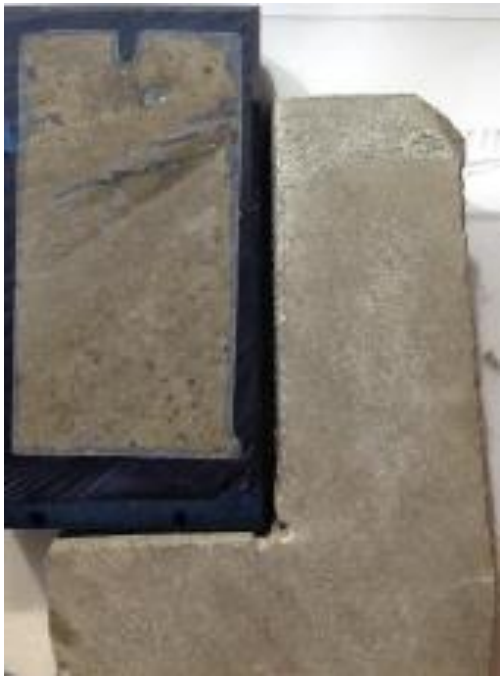
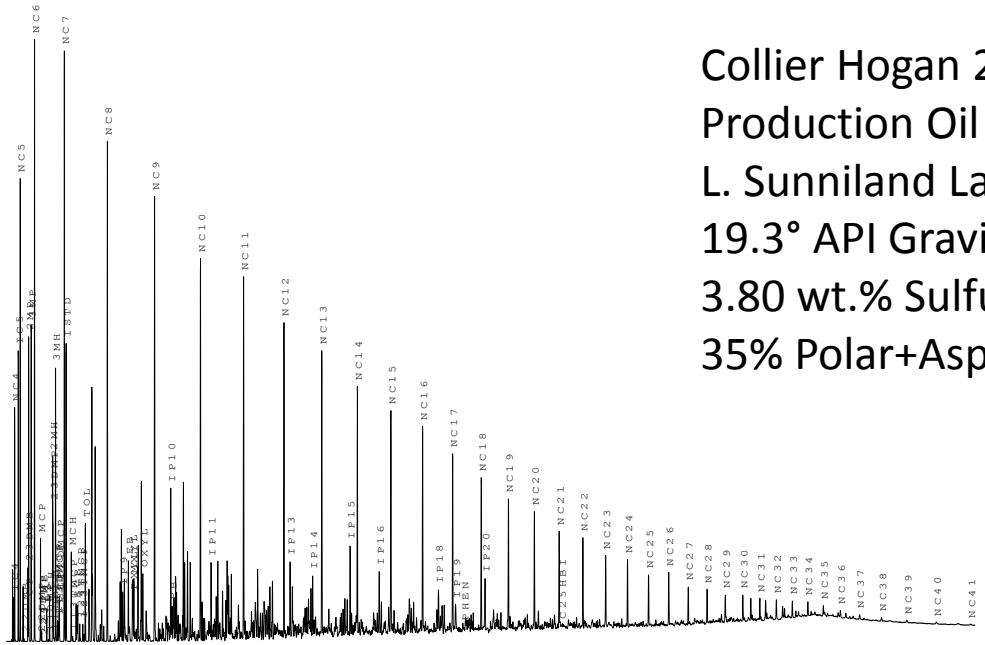
GC Fingerprint





Collier Hogan 20-3
Production Oil
L. Sunniland Lateral
19.3° API Gravity
3.80 wt.% Sulfur
35% Polar+Asphaltene

Extract gas chromatogram from production Oil sample in the Collier Hogan 20-3 well. Normal alkane envelope is is characterized by a dominant normal alkane envelope that is unimodal with maxima in the C7 range. Carbon Preference Index (CPI) is 0.91, indicating an even carbon predominance that is fairly typical of marine carbonate source rocks.

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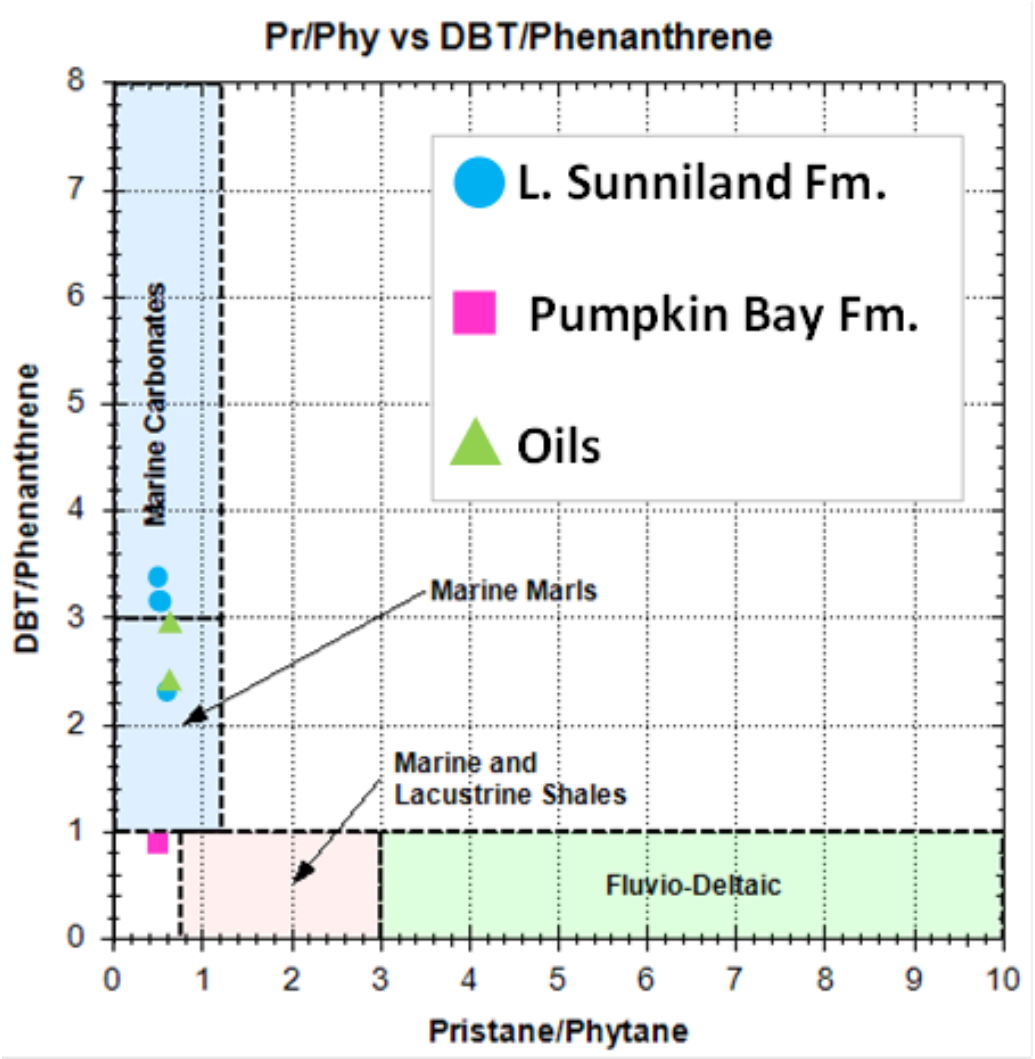
Biomarkers

Biomarker plot of Pristane/Phytane vs. Dibenzothiophene/Phenanthrene for the L. Sunnniland & Pumpkin Bay source rock extracts and related oils.

Most samples appear to plot in the marine carbonate and marl lithology zone and high DBT/Phen ratios are consistent with Type II-S kerogen.

Pumpkin Bay extract has lower DBT/Phen ratio which place it closer to marine shale lithology and it does not correlate with oils.



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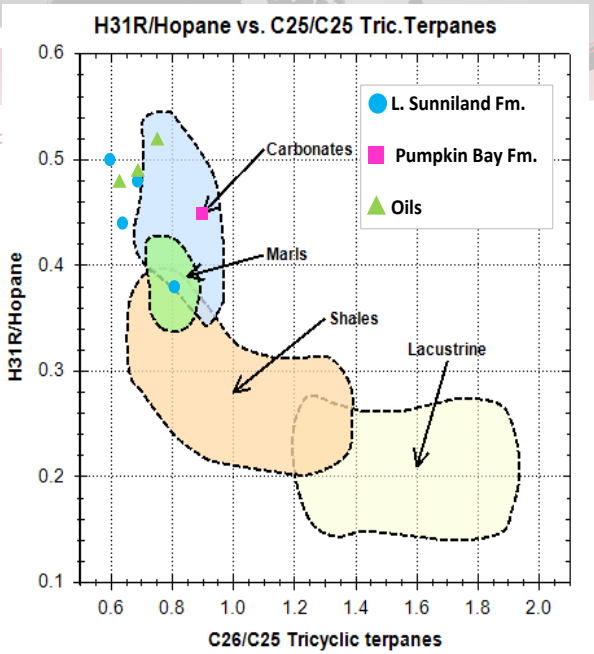
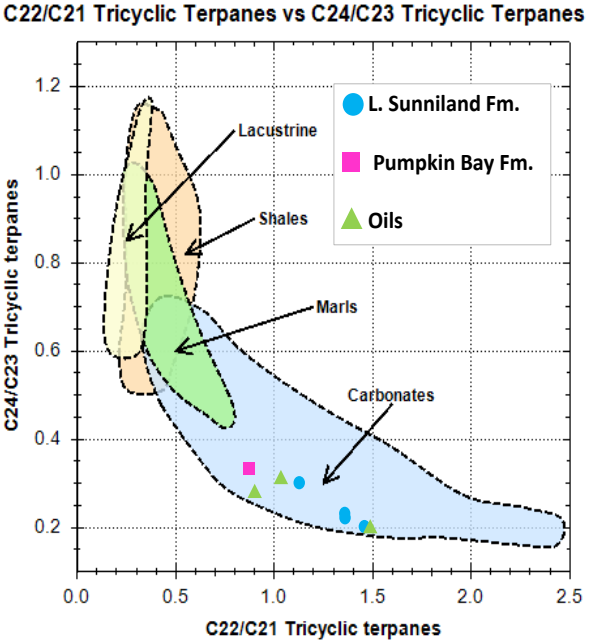
Biomarkers

Biomarker cross plots of various tricyclic terpane and hopane ratios can be used to distinguish source rock lithology and depositional environment for the L. Sunnniland & Pumpkin Bay source rock extracts and related oils.

Most samples appear to plot in the marine carbonate lithology zones, including the Pumpkin Bay extract.





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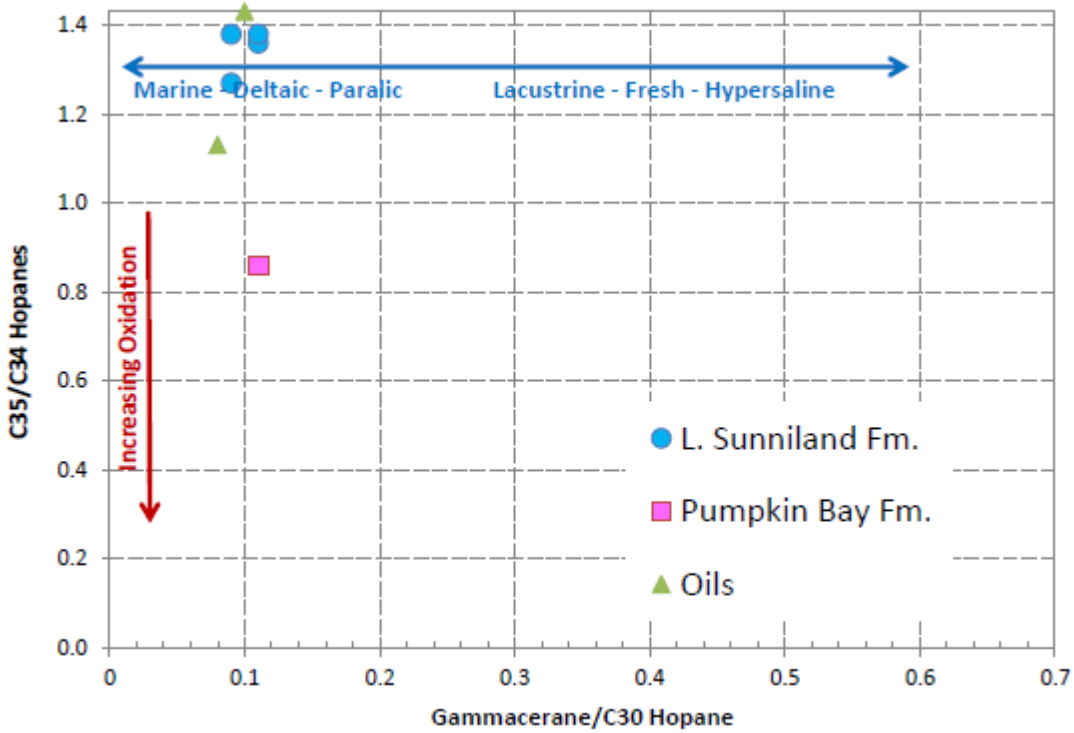
Biomarkers

Biomarker plot of Gammacerane/C30 Hopane versus C35/C34 Homohopane ratio.

High abundances of gammacerane indicates a stratified water column or hypersaline conditions.

High C35/C34 homohopane ratios suggest oil-prone rocks deposited in reducing environments and low ratios suggest gas-prone kerogens deposited in oxidizing environment.

Pumpkin Bay source rock extract is interpreted to represent a more oxic depositional environment.



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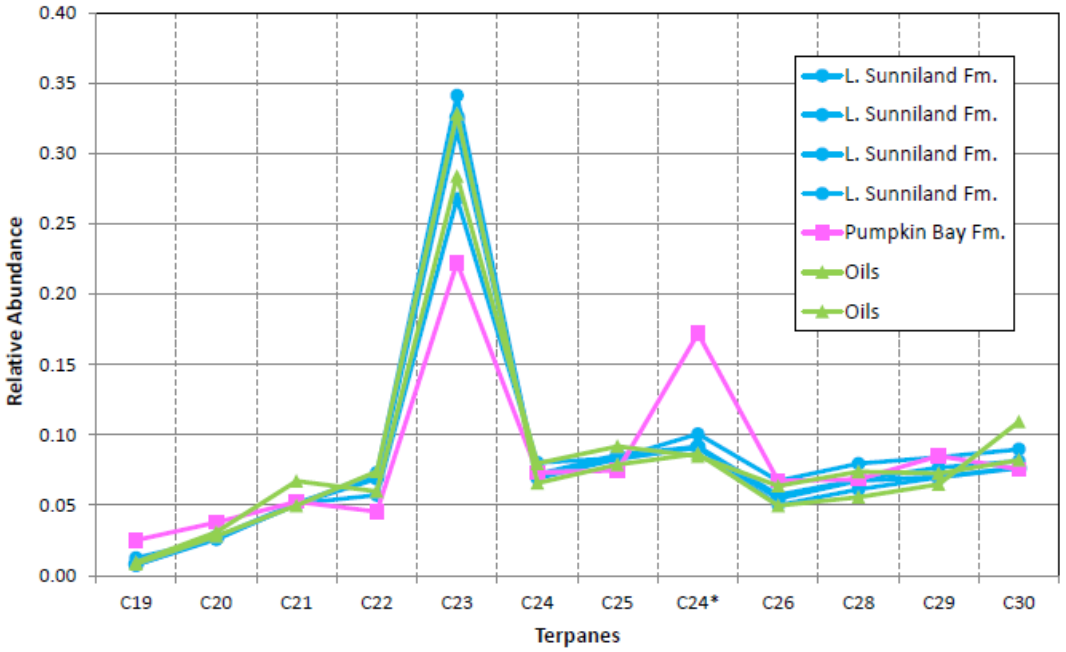
Biomarkers

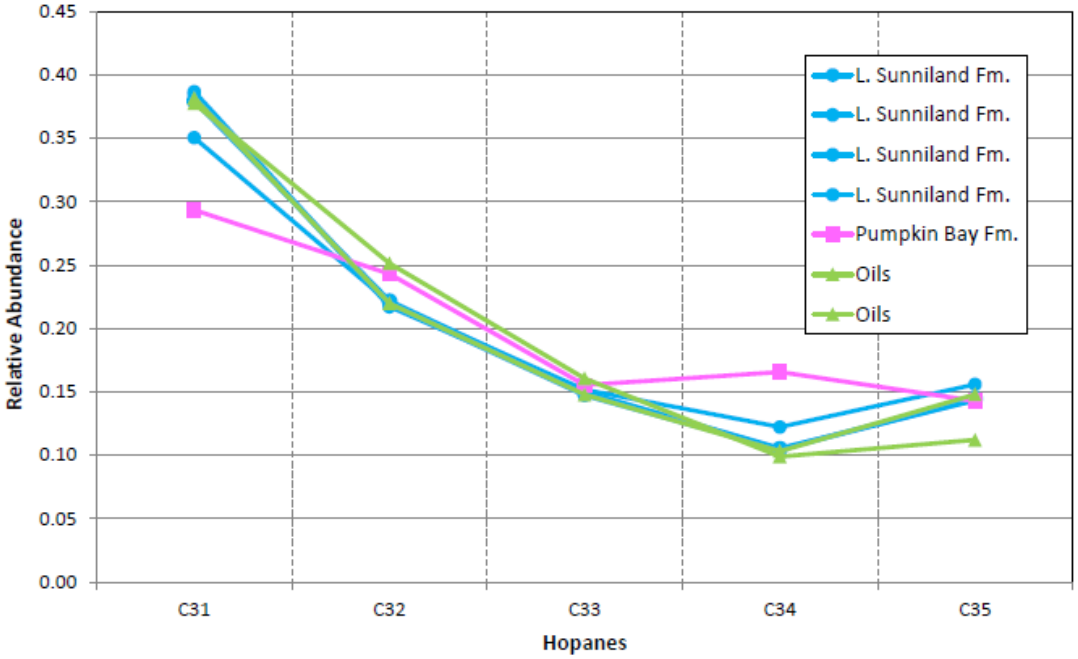
*Biomarker plots of the relative abundance of tricyclic and tetracyclic (denoted by *) terpanes (upper plot) and of the extended homohopanes (lower plot).*

Pumpkin Bay source rock extract has low C23 tricyclic and high C24 tetracyclic terpanes.

Pumpkin Bay source rock extract has relatively high C32 & C34 homohopanes.

Match features associated with lean U. Sunniland source rocks deposited in predominantly oxidizing depositional conditions (Palacas, et al., 1984).





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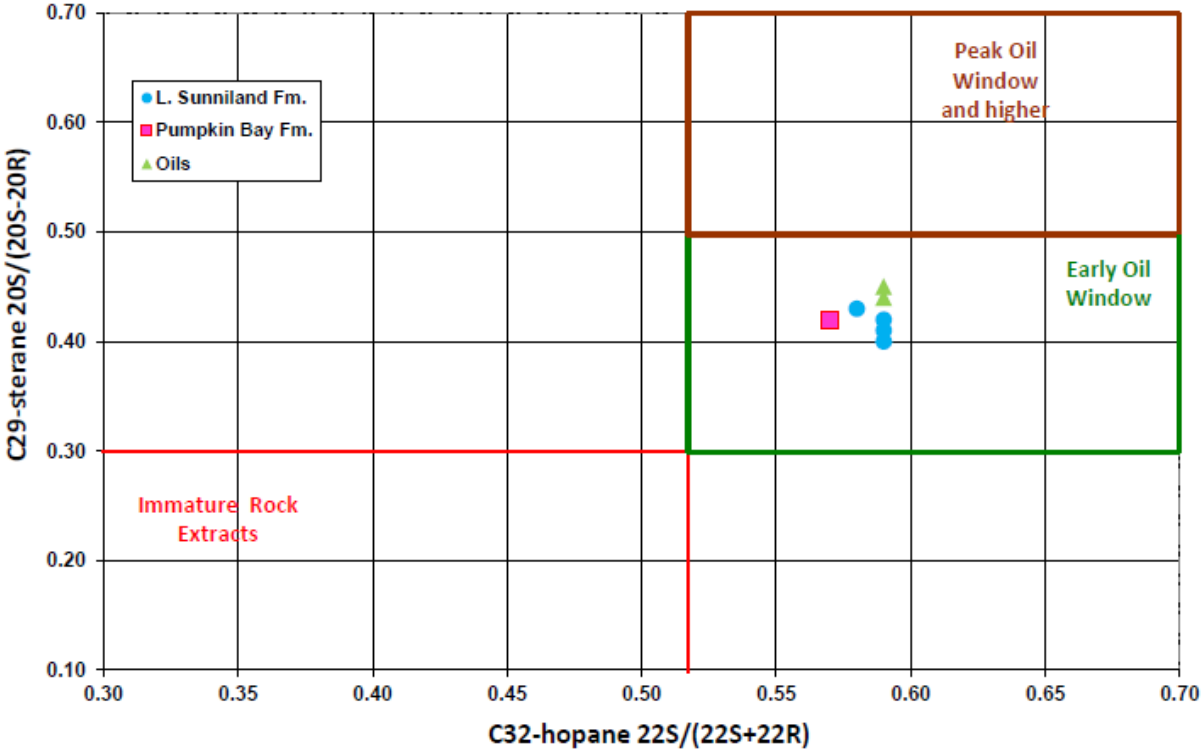
Biomarkers

Biomarker maturity plot of hopane and sterane epimerization ratios for the L. Sunnniland & Pumpkin Bay source rock extracts and related oils.

Samples appear to plot in the early oil region, although maturity zones shown are general and not specific to Type II-S kerogen.



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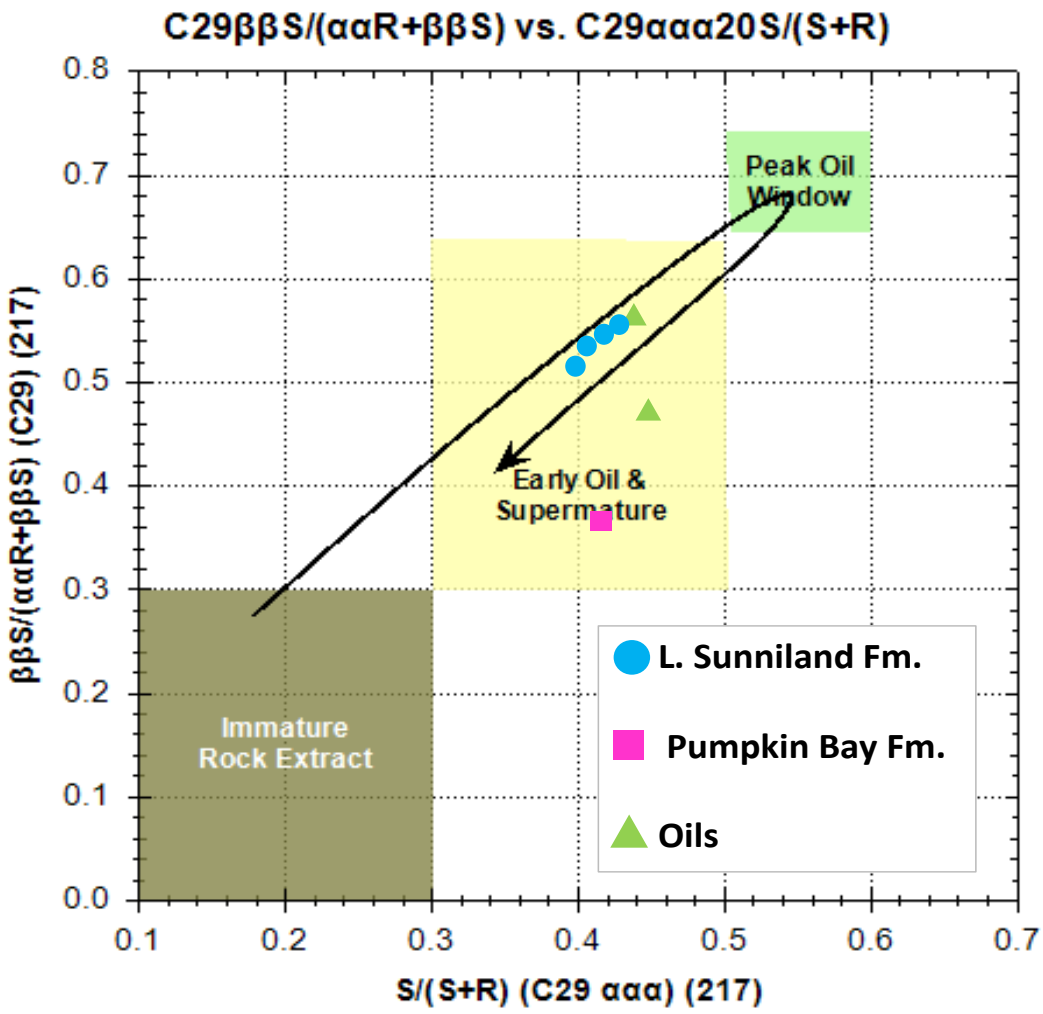
Biomarkers

Biomarker maturity plot of sterane isomerization and epimerization ratios for the L. Sunnniland & Pumpkin Bay source rock extracts and related oils.

Samples appear to plot in the early oil region, although maturity zones shown are general and not specific to Type II-S kerogen.



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SUMMARY

Well Name	Formation	Main Product	Thermal Maturity	Source Rock Richness	Organic Matter Type	Shale Oil Risk
Collier Hogan 20-3	L. Sunniland	*Estimated Original* →		*Good (1.57% TOC)*	*Oil-prone Type II-S*	Moderate
	Measured Currently →	Oil	Early Oil Window	Good (1.29% TOC)	Oil-prone Type II-S	

The Lower Sunniland Formation in the Collier Hogan 20-3 well is a good source rock (1.29 wt.% TOC) containing Type II-S oil-prone organic matter. It is interpreted to be in the early oil window (0.56% VRo), but some maturity parameters like the transformation ratio are below recommended minimum thresholds for shale oil and biomarker ratios indicate interval is early-mature.

Hydrocarbon yield calculations suggest moderate oil generation (77 bbl/a-ft) with low expulsion and moderate retained oil (52 bbl/a-ft). Recovered production oil from the Lower Sunniland is sulfur-rich (3.8 wt%) and heavy (API 19.1°), characteristics associated with low maturity oil in the early oil window.

On the basis of geochemistry, this is considered a MODERATE RISK for shale oil.

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SUMMARY

Well Name	Formation	Main Product	Thermal Maturity	Source Rock Richness	Organic Matter Type	Shale Oil Risk
Collier Hogan 20-3	Pumpkin Bay	Estimated Original →		Poor (0.33% TOC)	Gas-prone Type III/IV	High
	Measured Currently →	Trace Gas/Oil	Early Oil Window	Poor (0.23% TOC)	Gas-prone Type III/IV	

The Pumpkin Bay Formation in the Collier Hogan 20-3 wells is a poor source rock (0.23 wt.% TOC) containing Type III/IV gas-prone/inert organic matter. It is interpreted to be in the early oil window (0.68 VRo), but some maturity parameters like the transformation ratio are below recommended minimum thresholds for shale oil and biomarker ratios indicate interval is early-mature.

Hydrocarbon yield calculations trace oil generation (2 bbl/a-ft) with low in-situ oil saturation (2 bbl/a-ft). Unique homohopane biomarker patterns in the Pumpkin Bay extract appear to be useful for correlation and match features associated with lean source rocks deposited in oxidizing depositional conditions.

On the basis of geochemistry, this is considered a HIGH RISK for shale oil.

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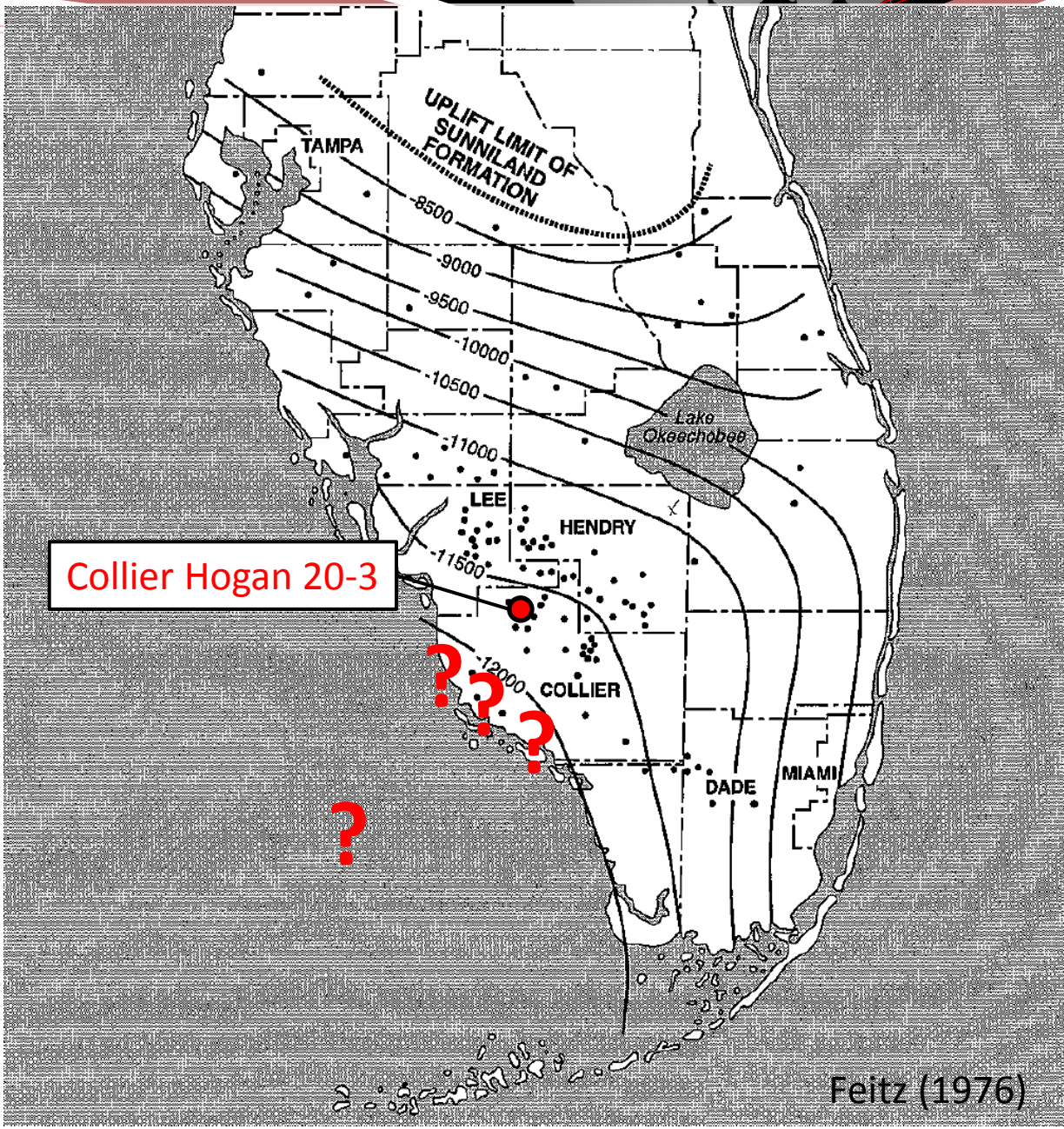
SUMMARY

Lower Sunniland Fm. appears to be too immature in the Collier Hogan 20-3 well.

Is it more prospective deeper in the South Florida Basin?

There are at least three wells drilled to the SW in Collier Co. that have apparently not been studied using modern geochemical analyses?

No geochemical data is available from the Sunniland in offshore Gulf of Mexico?



Feitz (1976)

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Summary Thoughts

- The Lower Sunniland is a fair-good source rock containing sulfur-rich, marine algal oil-prone Type II-S organic matter. In the Collier Hogan 20-3 well, it is in the early oil window and some maturity parameters are below minimum thresholds for shale oil. Hydrocarbon yield calculations suggest moderate oil generation with minimal oil expulsion. On the basis of geochemistry, it is considered a MODERATE RISK for shale oil in this location. Elsewhere in the South Florida Basin this source interval is likely to be more thermally mature and may be a more prospective target.

- The Pumpkin Bay is a poor source rock containing inert Type IV and gas-prone Type III organic matter based on limited sampling. It is in the incipient oil generation window in the Collier Hogan 20-3 well and likely at elevated maturity elsewhere in the South Florida Basin. Hydrocarbon yield calculations suggest trace amounts of hydrocarbon generation. On the basis of geochemistry, it is considered a HIGH RISK for shale oil development.

- The “movability” of the Lower Sunniland in-situ oil content is an additional risk factor in shale oil development. Pyrogram characteristics and organic petrology suggests that the in-situ oil may be heavy and immobile. Recovered production oil from the Collier Hogan 20-3 well is sulfur-rich (3.8 wt%) and heavy (API 19.1°), characteristics associated with low maturity oil in the early oil window.

- Biomarkers correlate the Collier Hogan 20-3 production oil with in-situ generation from the Lower Sunniland. Although the whole oil GC fingerprint showed abundant light hydrocarbons (carbon maximum at C7), bulk MPLC fractional analysis showed elevated polar+asphaltene content (35%), further suggesting that the in-situ oils may be relatively “immobile”.

Acknowledgements

- Dan A. Hughes Company
- Freeport-McMoRan Oil & Gas
- Wayne R. Knowles – organic petrology

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