Geochemical Characterization of the Upper Mississippian Goddard Formation, Springer Group, in the Anadarko Basin of Oklahoma

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Presented at the OGS 2020 “Shale Resource Plays of Oklahoma” Workshop

Introduction

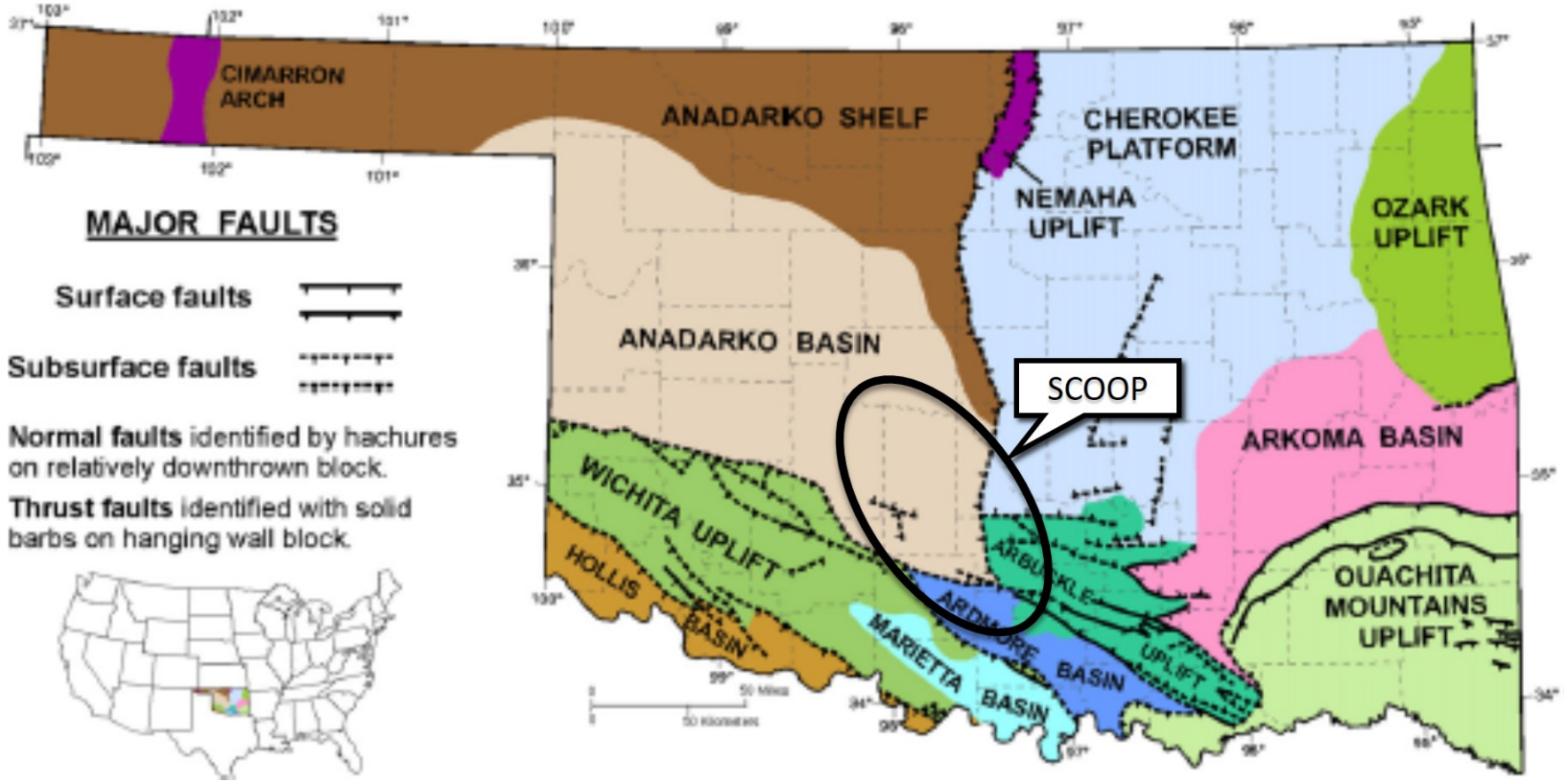
- **It is commonly assumed that the major source rock in Anadarko Basin is the Woodford shale. As a result when asked the source of an oil, the automatic response is typically Woodford, regardless of whether there is any supporting evidence for such an answer.**
- **The results presented in this study are related primarily to oils from the SCOOP play and possible sources for these oils.**
- **The geochemical data will show that the oils in the SCOOP do not have the classic Woodford signature and in all probability have a significant source contribution from the Goddard Formation.**
- **Pearson, C. and Philp, R. P. (2019). Geochemical Characterization of the Late Mississippian Goddard Formation, Springer Group, and Related Oils in the Anadarko Basin of Oklahoma. AAPG Bulletin, 103 (11), 2545–2571.**

Study Location

South Central Oklahoma Oil Province (SCOOP)

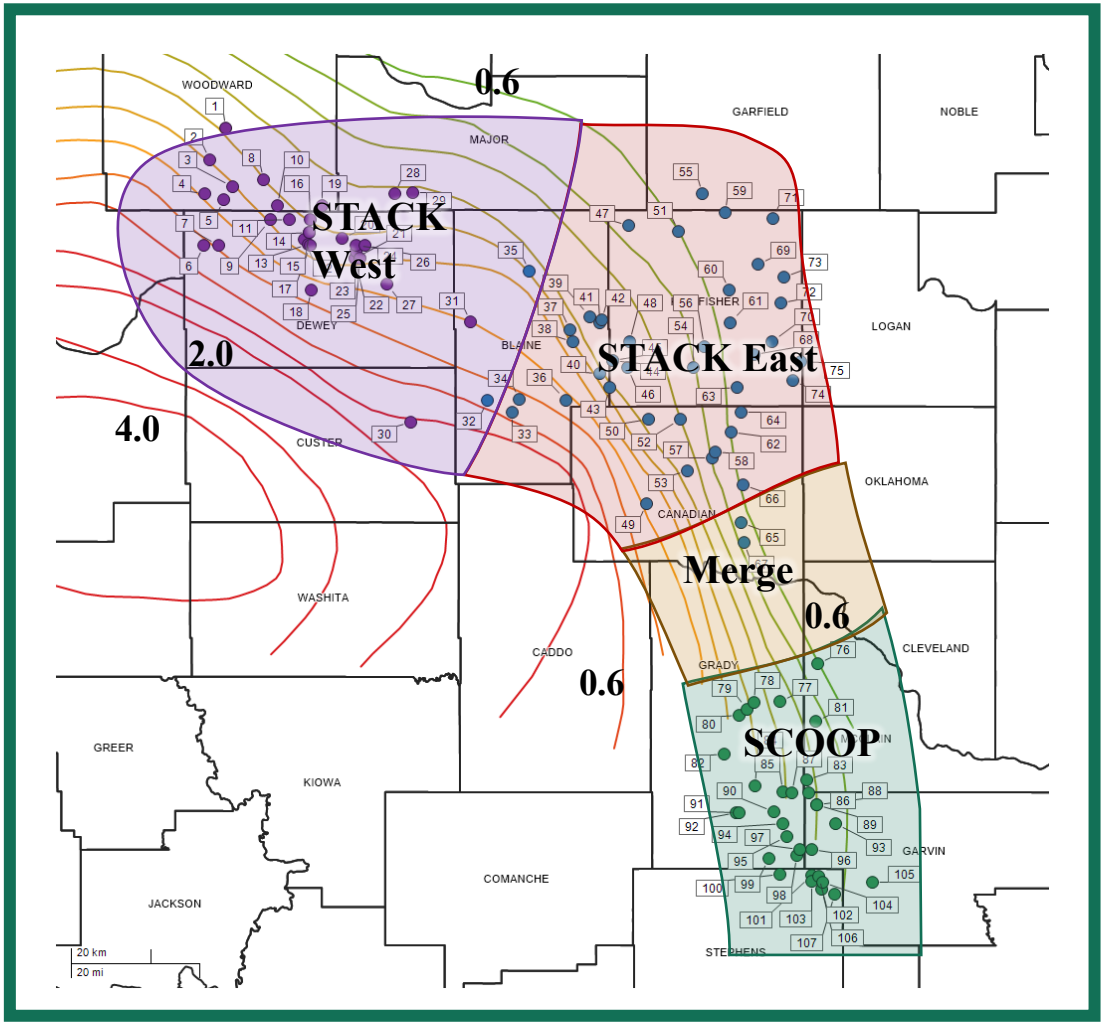
- Stacked play in Anadarko Basin

Goddard production in Garvin, Grady, and Stephens Co.



Map of major Oklahoma geologic provinces (modified from Cardott, 2012)

Complete Set of STACK and SCOOP Oils



- The SCOOP study is part of a much larger study involving 172 oils from the SCOOP and STACK plays.
- In this presentation only the SCOOP oils will be discussed.
- The STACK oils will be discussed in a separate publication.

The Goddard Formation and Previous Studies

- Basal unit of Springer Group
- Unconventional mudstone
- Present in Anadarko Basin and Ardmore Basin of Oklahoma

Jones and Philp (1990)

- Survey of Anadarko Basin; one “Springer” sample

Kim and Philp (2001)

- Study of Upper Mississippian source rocks in Anadarko Basin with abundant tricyclic terpanes

Wang and Philp (2001)

- Survey of Upper Mississippian and Pennsylvanian source rocks in Anadarko Basin, including the Springer.

Pearson and Philp (2019)

- Geochemical Characterization of the Late Mississippian Goddard Formation, Springer Group, and Related Oils in the Anadarko Basin of Oklahoma

Period	Series	Formation
Pennsylvanian	Missiourian	Hoxbar Sands
	Des Moinesian	Deese Sands
	Atokan	Atoka Sands
	Morrowan	Morrow Sands
Mississippian	Chesterian	Springer Sands
		Springer Shale Goddard
	Meramec	Caney Shale
	Osagean	Sycamore Limestone
Devonian	Middle – Upper	Woodford Shale
	Ulsterian	Hunton Limestone
Silurian	Cayugan	
	Niagaran	

http://www.jefferies.com/CMSFiles/Jefferies.com/files/Conferences/111114/Presentations/Teach%20In%20-%20SCOOP.pdf

A Brief Geochemical Overview

- Two major areas of investigation:
  - Characterization of **source rocks** in terms of organic richness, maturity of source rock, and oil or gas potential-Rock Eval
  - Characterization of organic compounds (biomarkers) in **oils and rock extracts** to provide information on source, maturity, depositional environments, migration etc.
- Rock Eval provides an indication of the total organic carbon-(richness); Tmax-(maturity); Hydrogen index (type and potential of organic matter).
- Biomarkers derived from original source components and also extremely useful for undertaking oil/source rock correlations.

Sample Set

- 11 oils
- 15 core samples
- 1 outcrop
- 1 asphalt

Anadarko Basin

Ardmore Basin

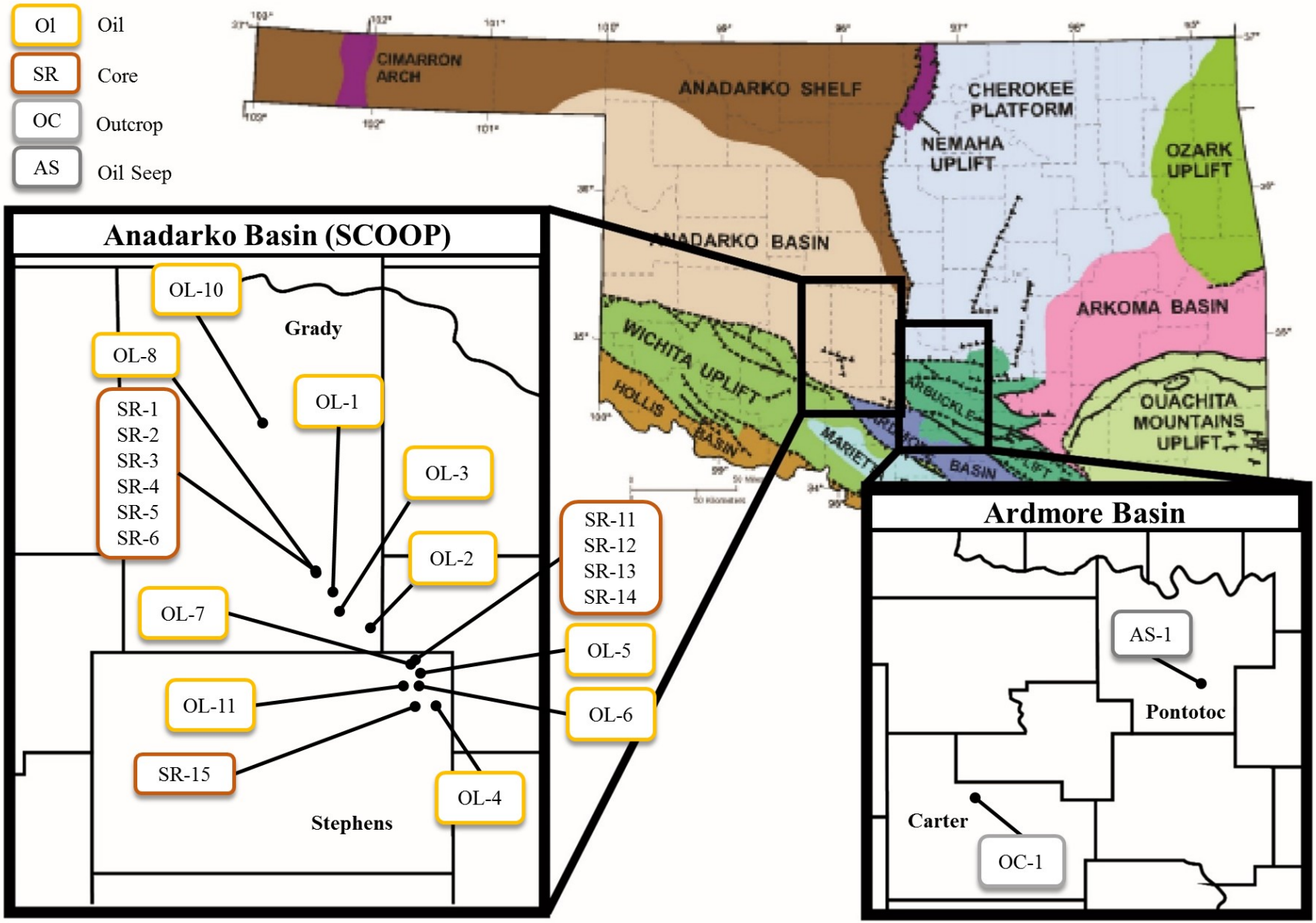
ID	Type	County	Section	Township	Range	Depth (ft)
OI-1	Oil	Grady	28	4N	5W	11801
OI-2	Oil	Grady	13	3N	5W	11923
OI-3	Oil	Grady	3	3N	5W	12070
OI-4	Oil	Stephens	23	2N	4W	10724
OI-5	Oil	Stephens	16	2N	4W	13264
OI-6	Oil	Stephens	21	2N	4W	13736
OI-7	Oil	Stephens	9	2N	4W	11934
OI-8	Oil	Grady	20	4N	5W	12961
OI-9*	Oil	Grady				
OI-10	Oil	Grady	26	7N	6W	11965
OI-11	Oil	Stephens	5	2N	4W	12004
SR-1	Whole Core	Grady	17	4N	5W	13045
SR-2	Whole Core	Grady	17	4N	5W	13035
SR-3	Whole Core	Grady	17	4N	5W	12965
SR-4	Whole Core	Grady	17	4N	5W	13010
SR-5	Whole Core	Grady	17	4N	5W	12945
SR-6	Whole Core	Grady	17	4N	5W	13074
SR-7**	Sidewall Core	Grady				12606
SR-8**	Sidewall Core	Grady				12549
SR-9**	Sidewall Core	Grady				12418
SR-10**	Sidewall Core	Grady				12351
SR-11	Sidewall Core	Stephens	4	2N	4W	13040
SR-12	Sidewall Core	Stephens	4	2N	4W	13067
SR-13	Sidewall Core	Stephens	4	2N	4W	13090
SR-14	Sidewall Core	Stephens	4	2N	4W	13104
SR-15	Whole Core	Stephens	7	4N	1W	7204
OC-1	Outcrop	Pontotoc	30	2N	7E	2
AS-1	Asphalt	Carter	S11	3S	R1	0

* Exact location and depth unknown. The well for OI-9 is within a mile of the well for OL-8.

** Exact location and well name for core unknown.

Sample Locations*

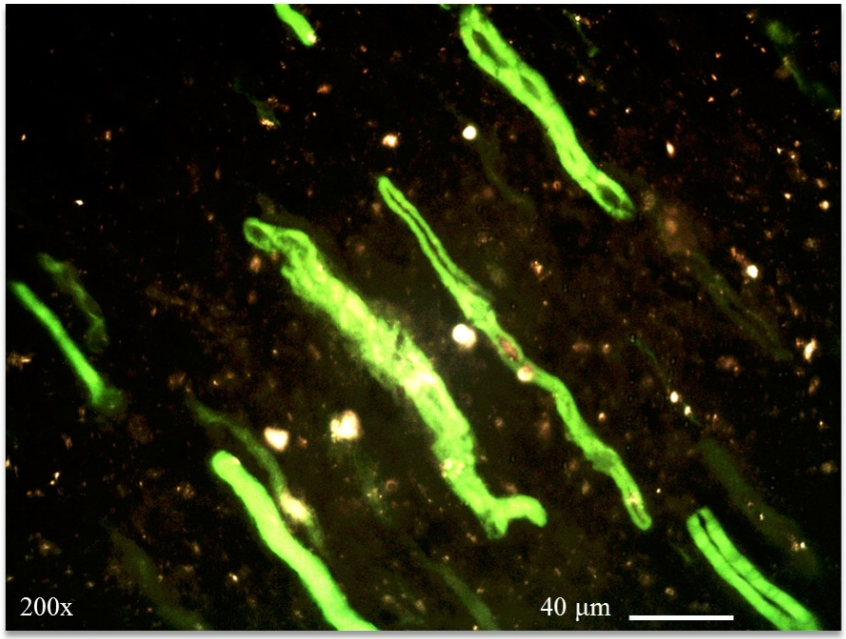
*OL-9 and SR-7 to SR-10 not shown

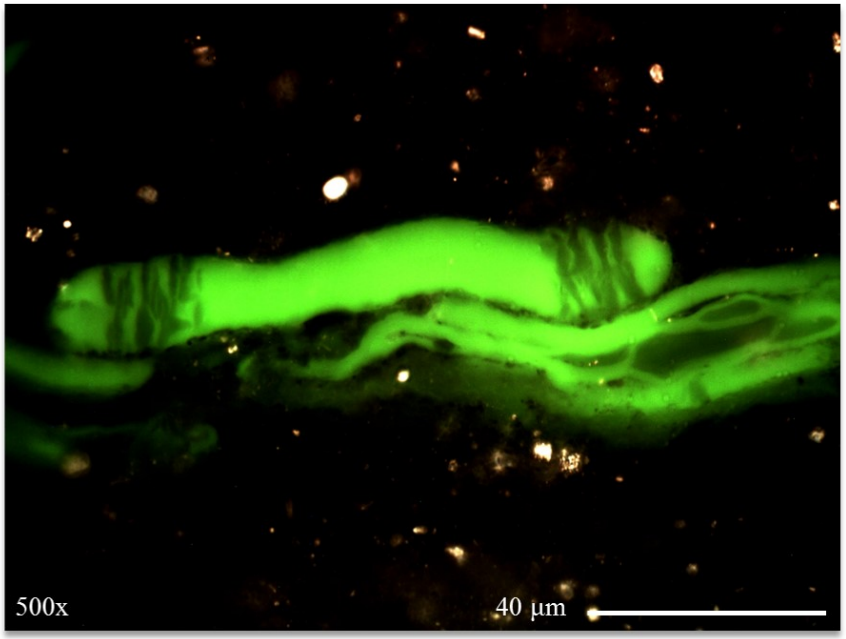


Map of Oklahoma geologic provinces (modified from Cardott, 2012)

Tasmanite Abundance

- Moderate abundance in OC-1-Woodford outcrop
- Relatively low abundance in SR-14-Goddard



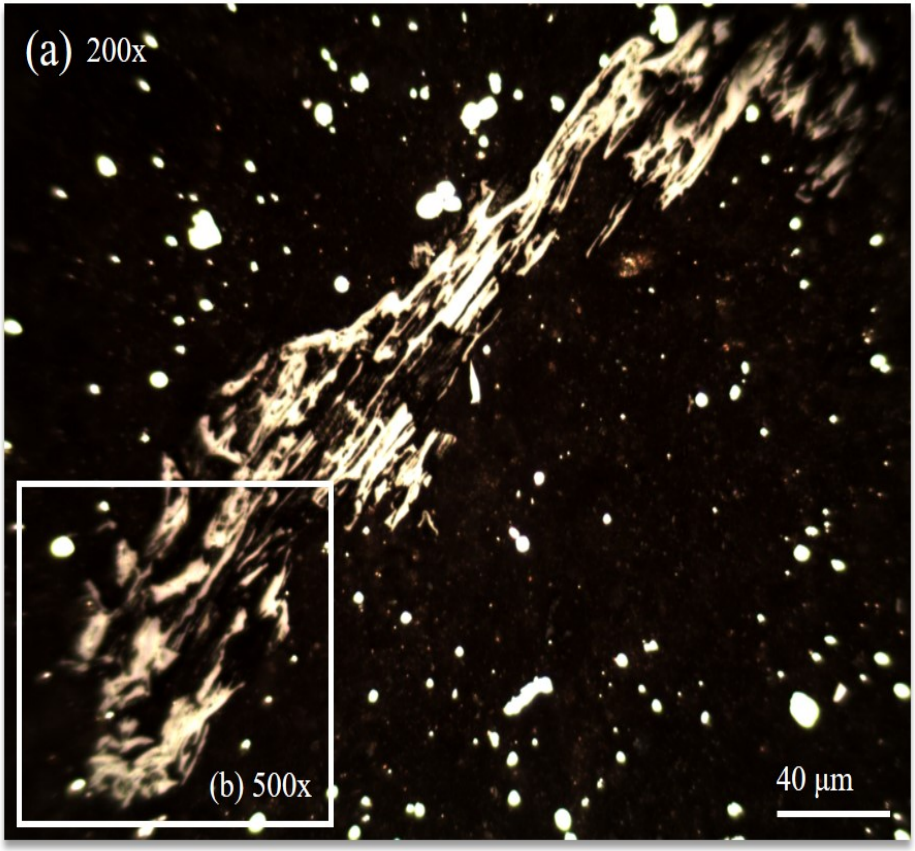


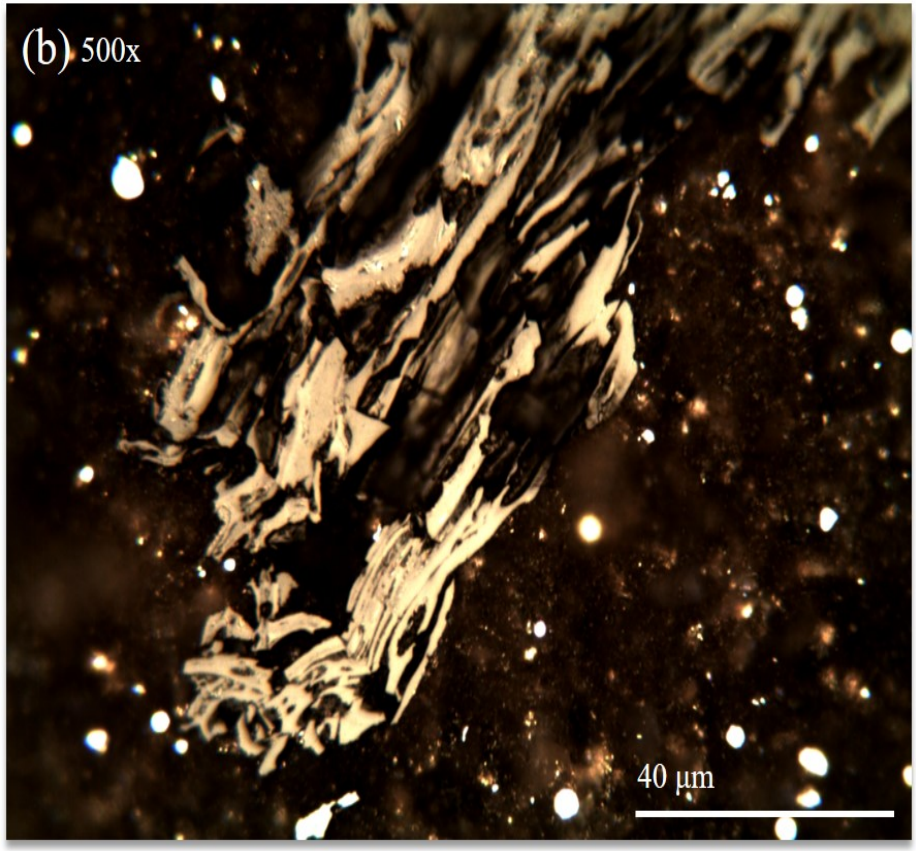
Tasmanite **images provided courtesy of B. Cardott (2016)**

Presence of Fusinite and PAHs

Fusinite and Polycyclic aromatic hydrocarbons (PAHs)

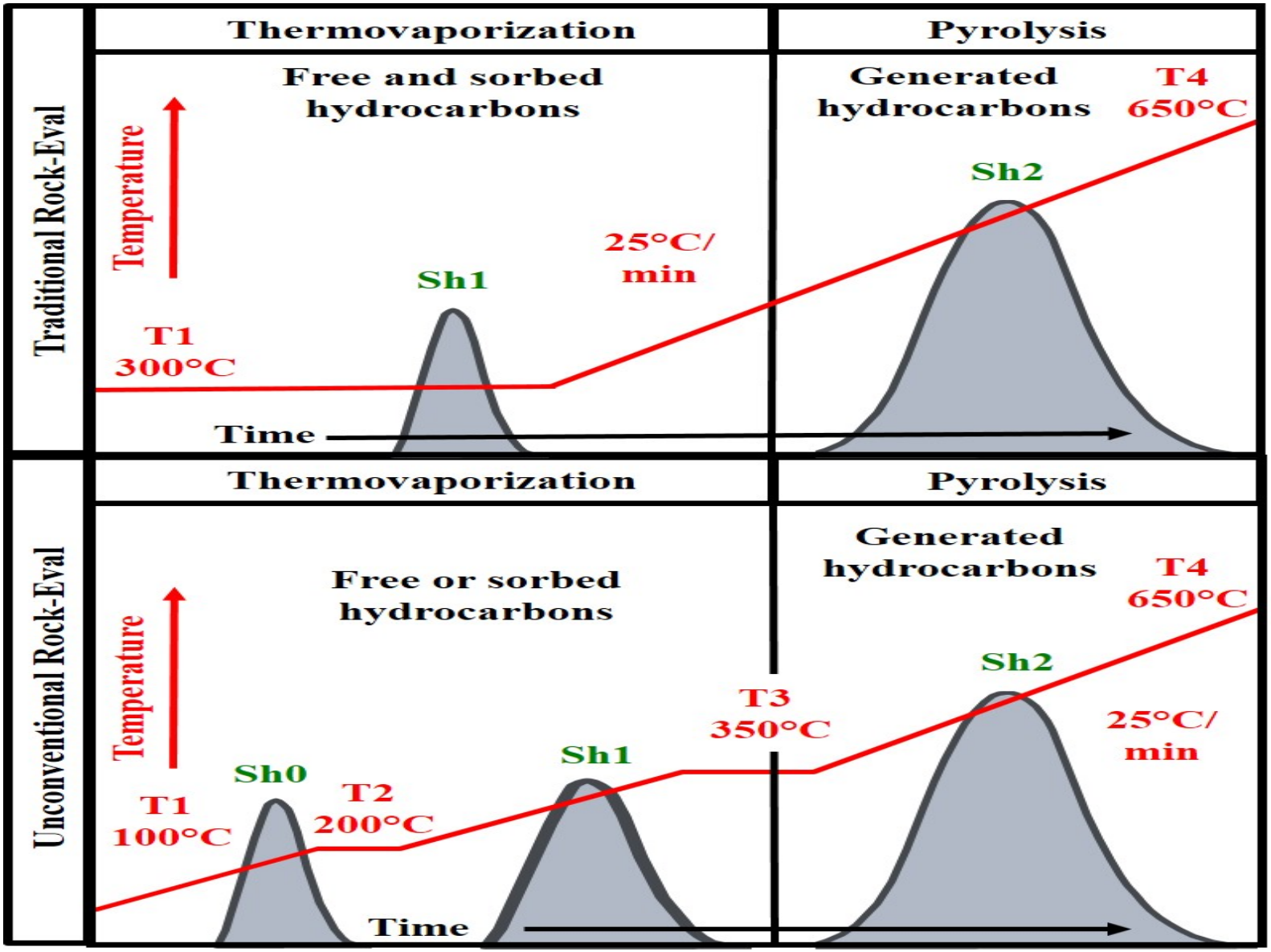
- Suggests terrestrial input and occurrence of forest fires
- PAHs in oils and source rocks; fusinite in SR-15





Fusinite images provided courtesy of B. Cardott (2016)

Typical Rock Eval Pyrograms



Rock-Eval Data

Sample	TOC[1]	Sh0[2]	Sh1[3]	S1[4]	S2[5]	S3[6]	Tmax[7]	%Ro[8]*	HI[9]	OI[10]	CC[11]
OC-1	3.15			1.95	70.42	0.88	427	0.53 (0.60)	770	10	4.45
SR-1	4.45			8.73	8.25	0.65	449	0.92	185	15	2.56
SR-2	5.85			7.32	11.38	0.68	450	0.94	195	12	4.33
SR-3	6.51			13.12	14.28	0.79	445	0.85	219	12	4.85
SR-4	7.77			9.49	17.81	0.83	447	0.89	229	11	5.19
SR-5	0.86			0.75	0.75	0.50	445	0.85	88	58	48.26
SR-6	1.68			0.29	0.65	0.18	460	1.12	39	11	4.61
SR-7	0.74	0.22	0.59	0.81	1.65		457	1.08	223	9	
SR-8	1.46	1.43	0.91	2.34	1.35		461	1.15	92	5	
SR-9	3.15	0.72	1.81	2.53	4.40		460	1.13	140	3	
SR-10	3.55	0.97	2.15	3.12	4.10		460	1.13	115	3	
SR-11	5.51	3.77	6.19	9.96	10.44		445	0.86	189	1	
SR-12	6.26	6.99	6.61	13.60	9.11		452	0.99	146	2	
SR-13	7.43	5.74	7.95	13.69	12.60		450	0.95	170	2	
SR-14	5.80	5.15	7.99	13.14	10.11		450	0.95 (1.04)	174	1	

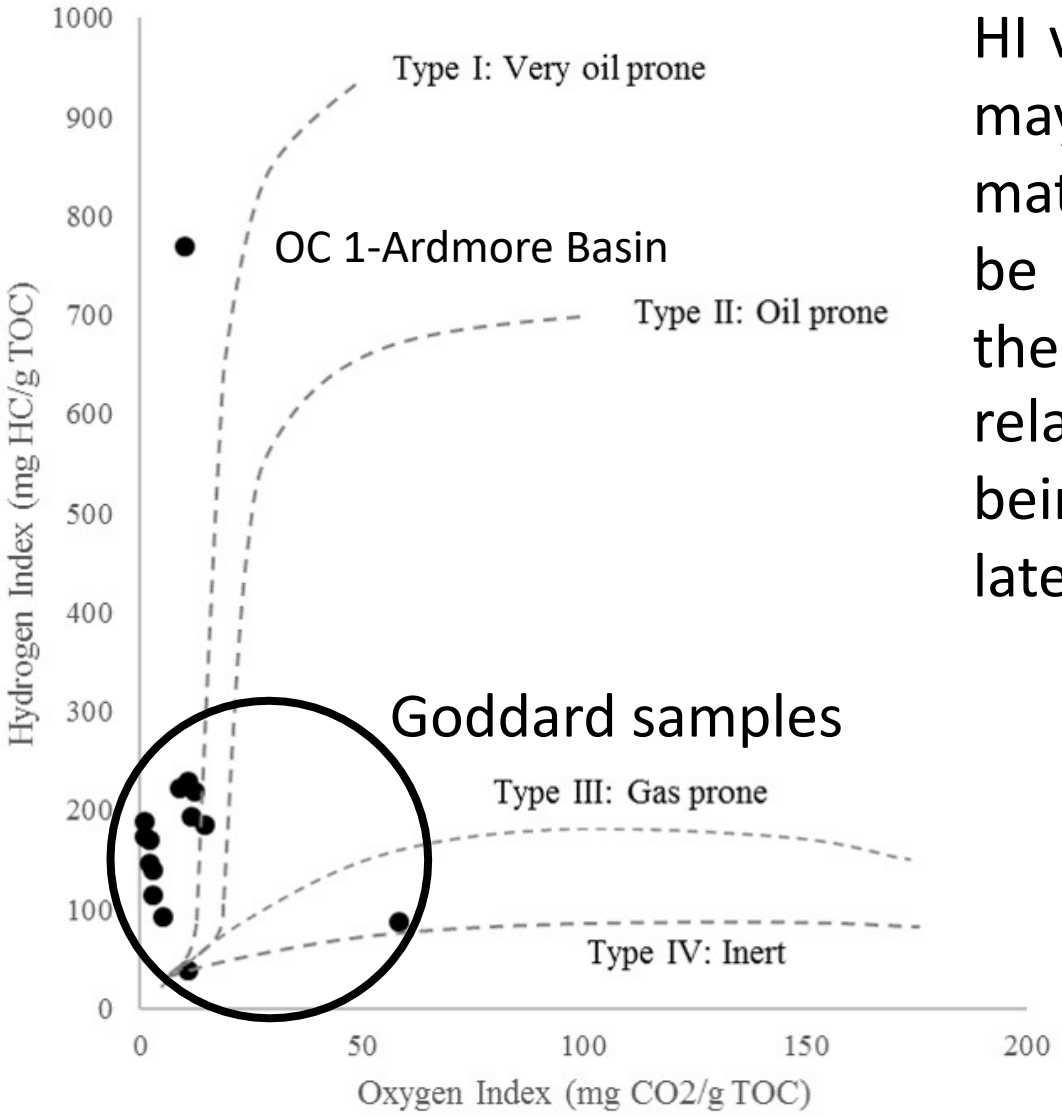
OC-1 and SR-1 to SR-6 analyzed using traditional Rock-Eval

SR-7 to SR-14 analyzed using unconventional Rock-Eval. S3 and CC data not provided by IFP Energies nouvelles

*Calculated using the formula %Ro (from Tmax) = 0.0180 x Tmax – 7.16 (Jarvie et al., 2005). Values in parentheses were manually measured.

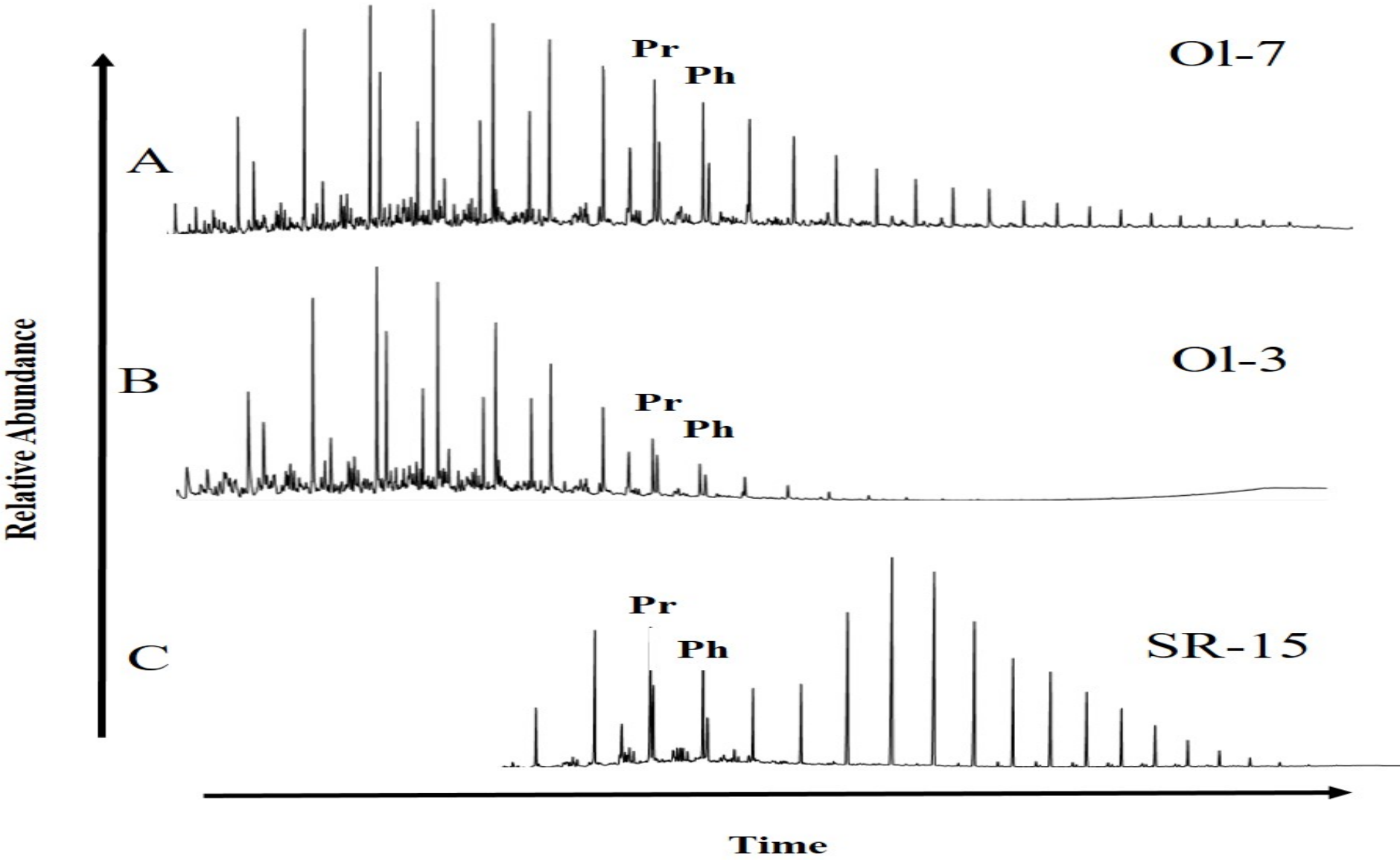
1.Total organic carbon (wt. %), 2. Free hydrocarbons (mg HC/g rock), 3. Sorbed hydrocarbons (mg HC/g rock), 4. Free and sorbed hydrocarbons (mg HC/g rock), 5. Remaining hydrocarbon potential of kerogen (mg HC/g rock), 6. Oxygen content of sample (mg CO_2/g rock, 7. Temperature of maximum S2 evolution (°C), 8. Vitrinite Reflectance, 9. Hydrogen Index (mg HC/g TOC), 10. Oxygen Index of sample (mg CO2/g TOC), 11. Carbonate Content (wt %)

Goddard Rock Eval Data

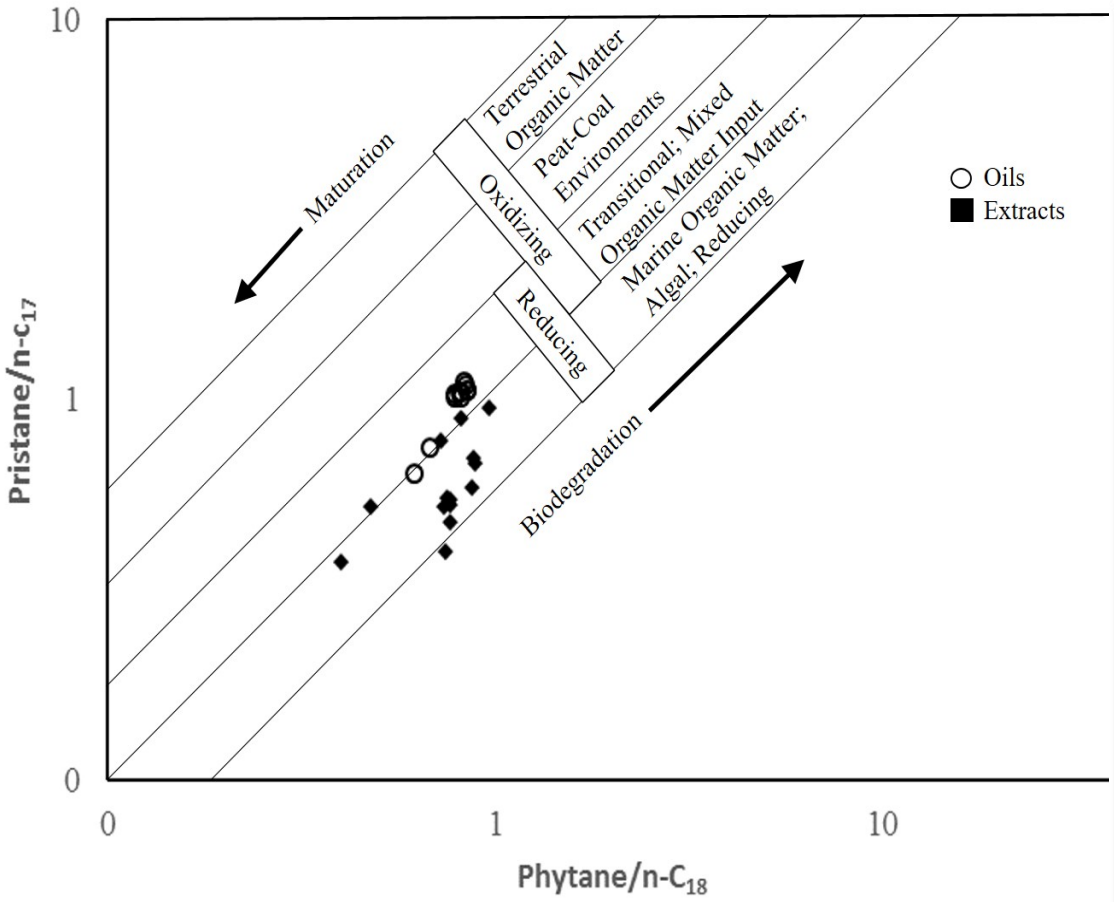


HI values for Goddard may appear low but maturity also has to be considered and these samples are relatively mature being in the mid to late oil window.

Saturate Fraction Chromatograms



n-Alkanes and Isoprenoids



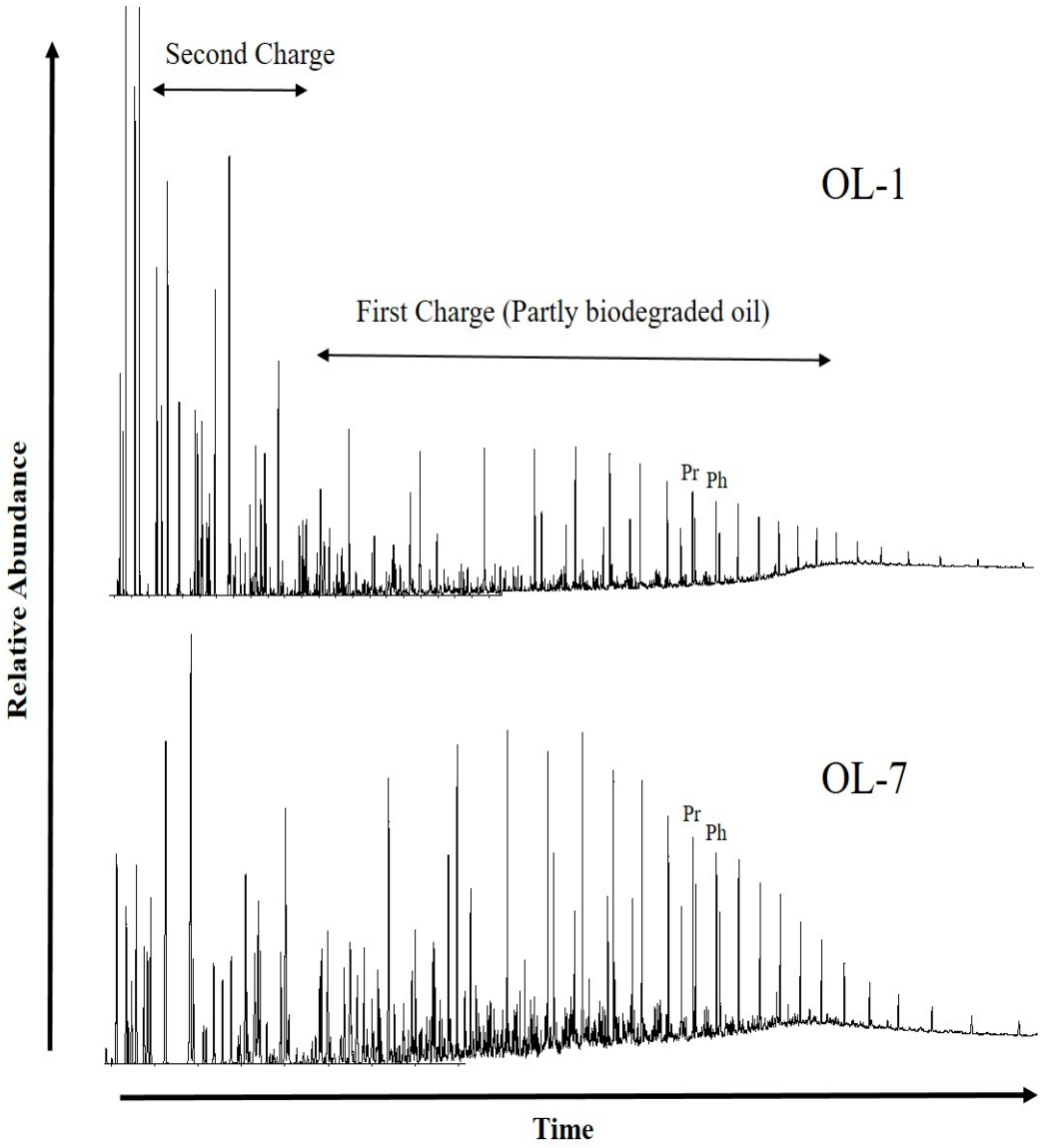
Sample	Type	Pr/Ph	Pr/C_{17}	Ph/C_{18}
Ol-1	Oil	1.3	1.1	0.8
Ol-2	Oil	1.4	1.1	0.8
Ol-3	Oil	1.9	1.1	0.8
Ol-4	Oil	1.3	1.1	0.8
Ol-5	Oil	1.4	1.0	0.8
Ol-6	Oil	1.4	1.0	0.8
Ol-7	Oil	1.4	1.1	0.8
Ol-8	Oil	1.3	1.1	0.8
Ol-9	Oil	1.4	1.0	0.8
Ol-10	Oil	1.2	0.6	0.6
Ol-11	Oil	1.3	0.7	0.7
SR-1	Whole Core	1.2	0.8	0.7
SR-2	Whole Core	0.9	0.6	0.9
SR-3	Whole Core	1.5	0.4	0.4
SR-4	Whole Core	1.0	0.7	0.9
SR-5	Whole Core	1.3	0.9	0.8
SR-6*	Whole Core			
SR-7*	Sidewall Core			
SR-8	Sidewall Core	0.8	0.4	0.7
SR-9	Sidewall Core	0.9	0.5	0.8
SR-10	Sidewall Core	1.0	0.7	0.9
SR-11	Sidewall Core	0.9	0.6	0.8
SR-12	Sidewall Core	0.9	0.5	0.8
SR-13	Sidewall Core	0.9	0.5	0.8
SR-14	Sidewall Core	0.9	0.5	0.7
SR-15	Whole Core	1.8	0.5	0.5
OC-1	Outcrop	1.3	1.0	1.0
AS-1*	Asphalt			

*Data not available

Source Rock Summary

- Rock Eval data indicate Goddard samples have reasonable TOC content; HI values are relatively low but samples are relatively mature.
- GC data including n-alkanes and isoprenoids primarily indicate a marine source of organic matter deposited under relatively reducing conditions favoring preservation of the organic matter.
- Petrographic data support the presence of varying amounts of Tasmanites and relatively low abundance of terrestrial source material in some samples.
- Next step evaluate possible relationships between source rocks and oils.

Crude Oil Chromatograms



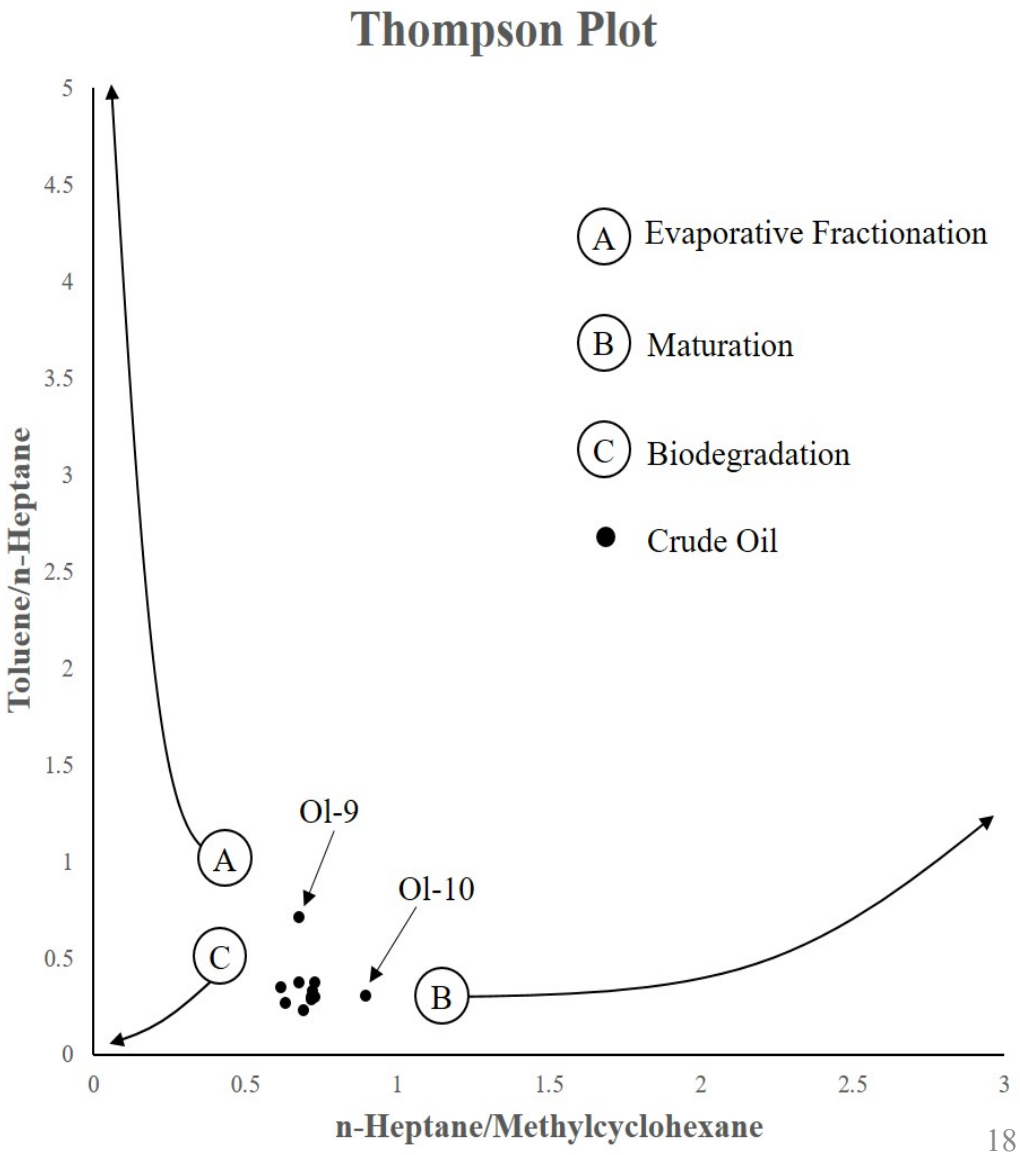
No indication oils are currently heavily biodegraded.

Possible there may have be previous episodes of biodegradation

Indications of possible mixing of slightly degraded oils and lighter more mature condensates.

Fractionation: C_7 Isomers

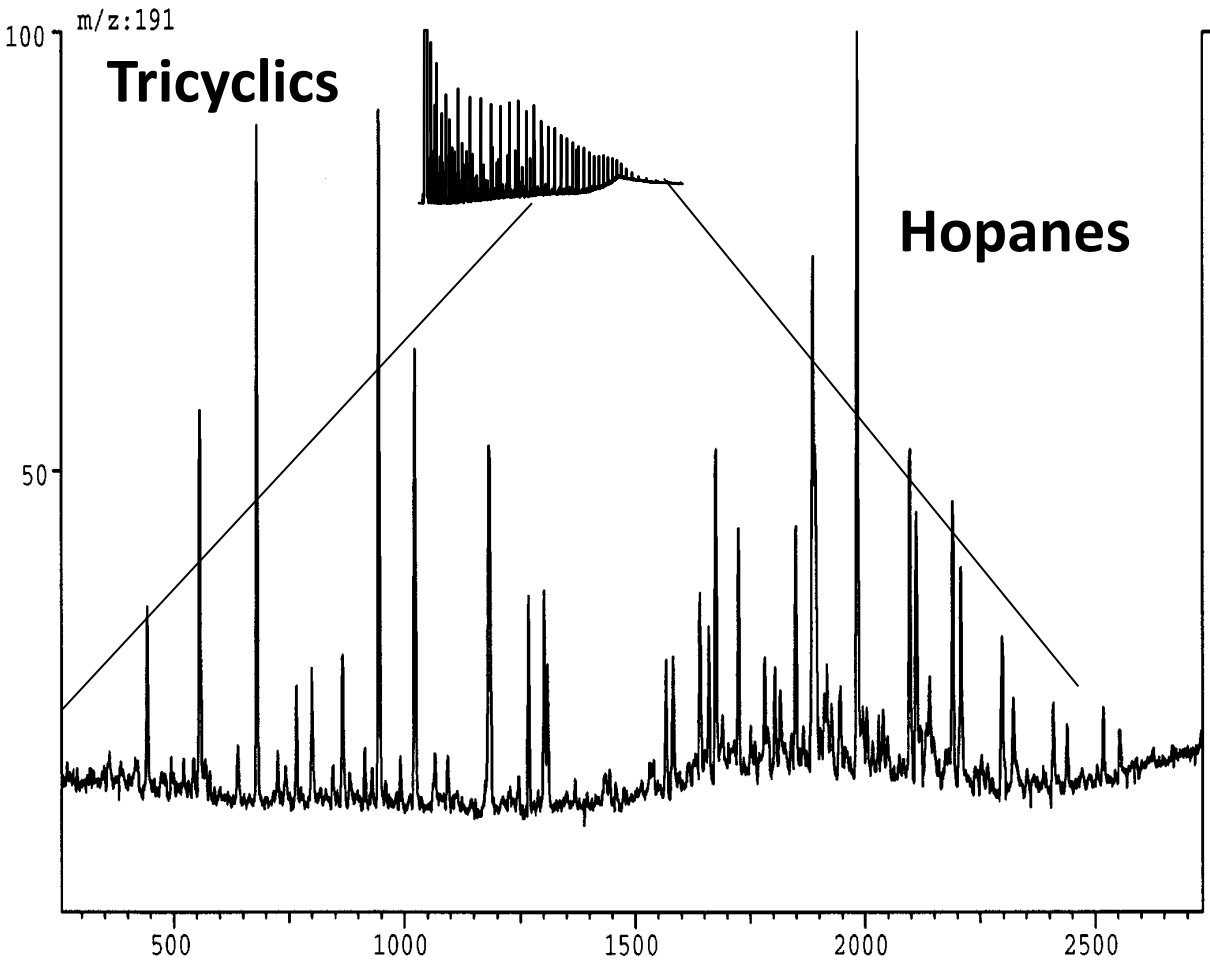
- Aromaticity vs. paraffinicity
- Most oils fall within “normal” range
- Ol-9 plots along fractionation trend
- Ol-10 plots along maturation trend



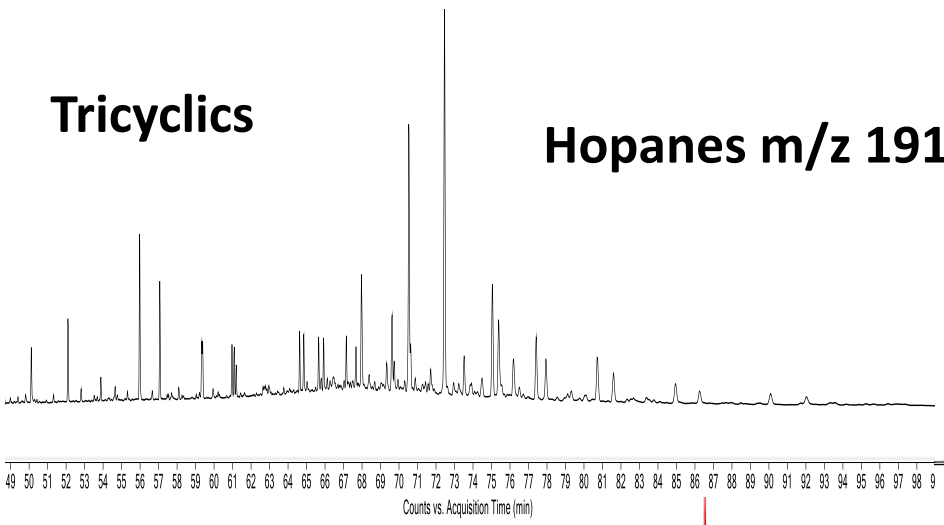
After Thompson (1987)

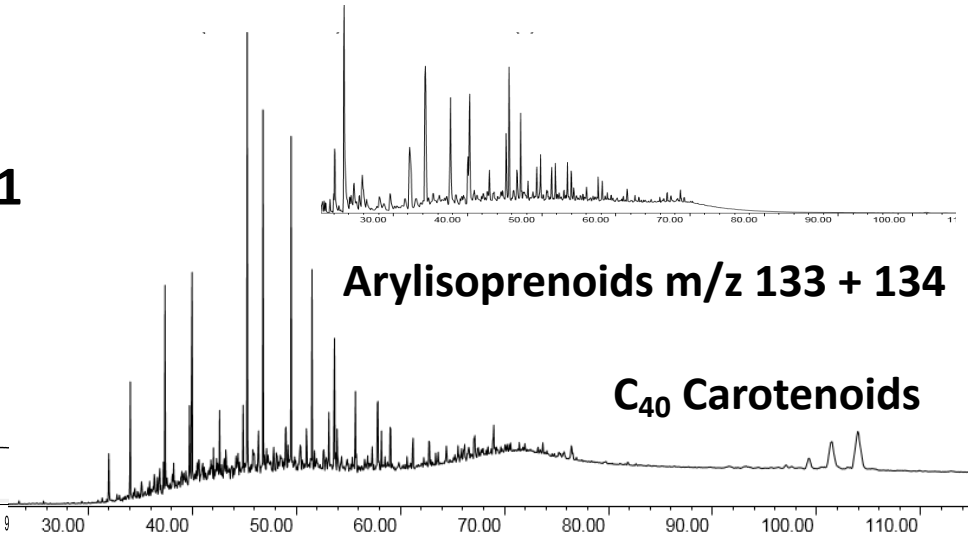
Biomarker Chromatograms

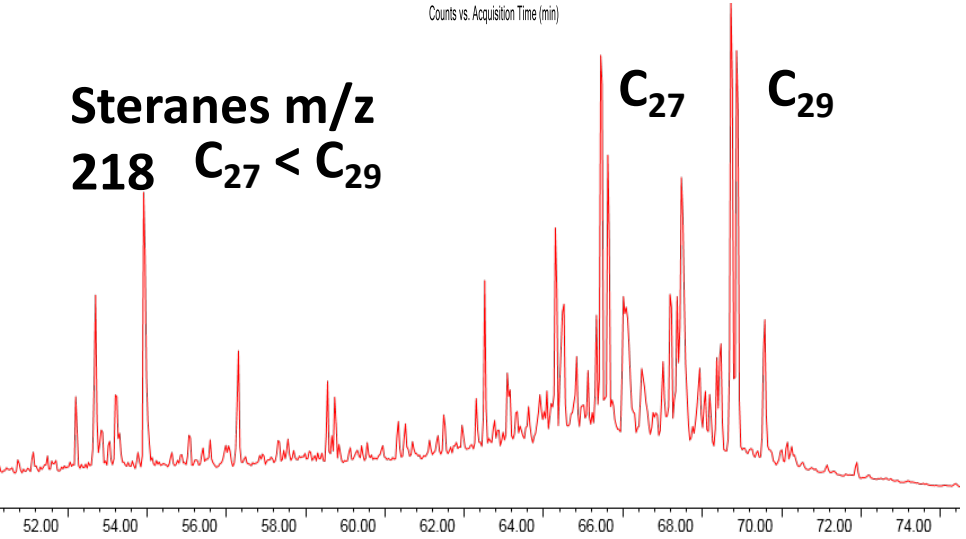
Biomarkers are complex organic compounds present in low concentrations in oils and source rocks. Their fingerprints are invaluable in undertaking oil/source rock correlations and providing information on source, maturity, depositional environments, biodegradation. Generally not visible on gas chromatograms so need to use a more sophisticated analytical approach.



Classic Woodford Biomarker Fingerprints

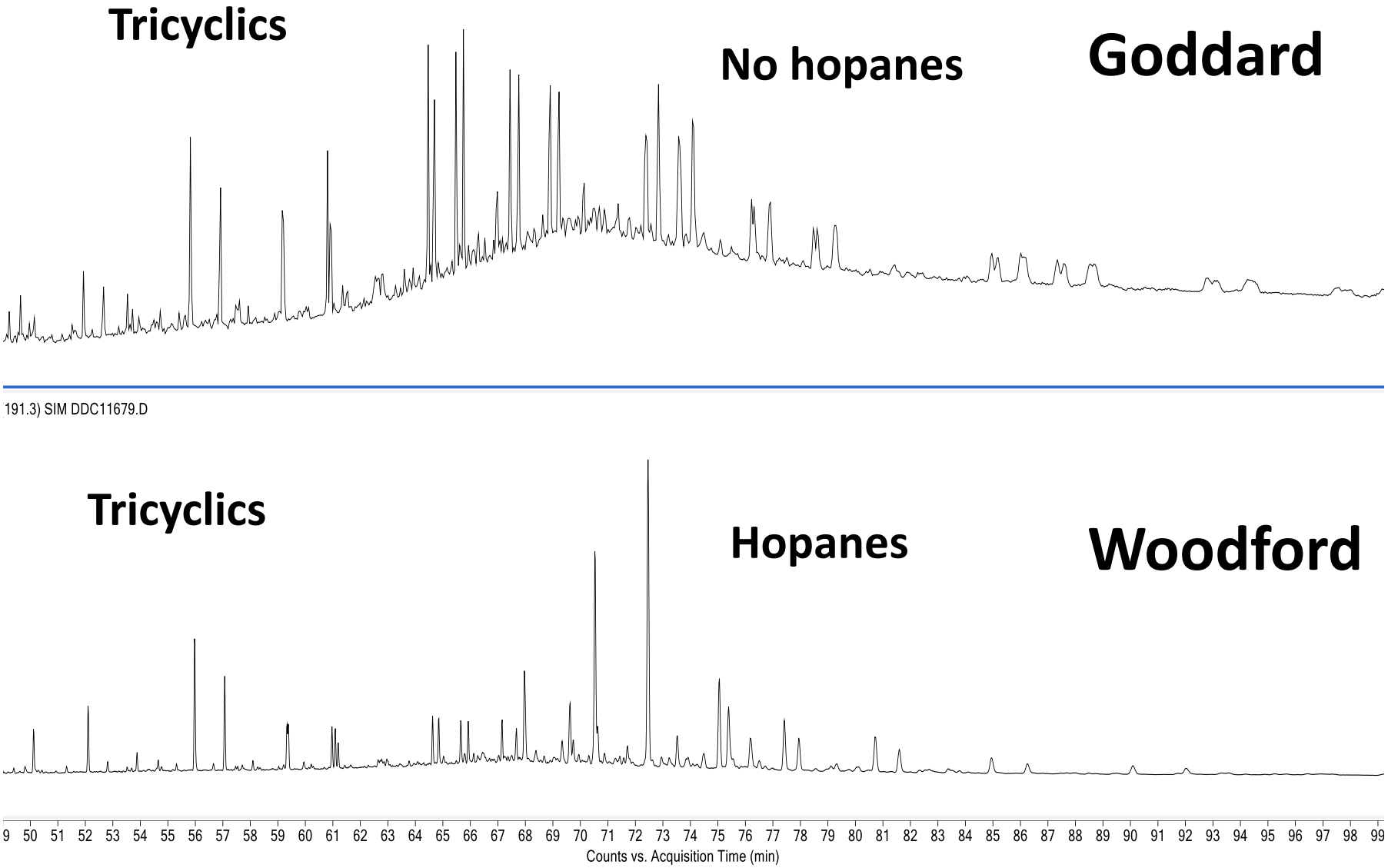




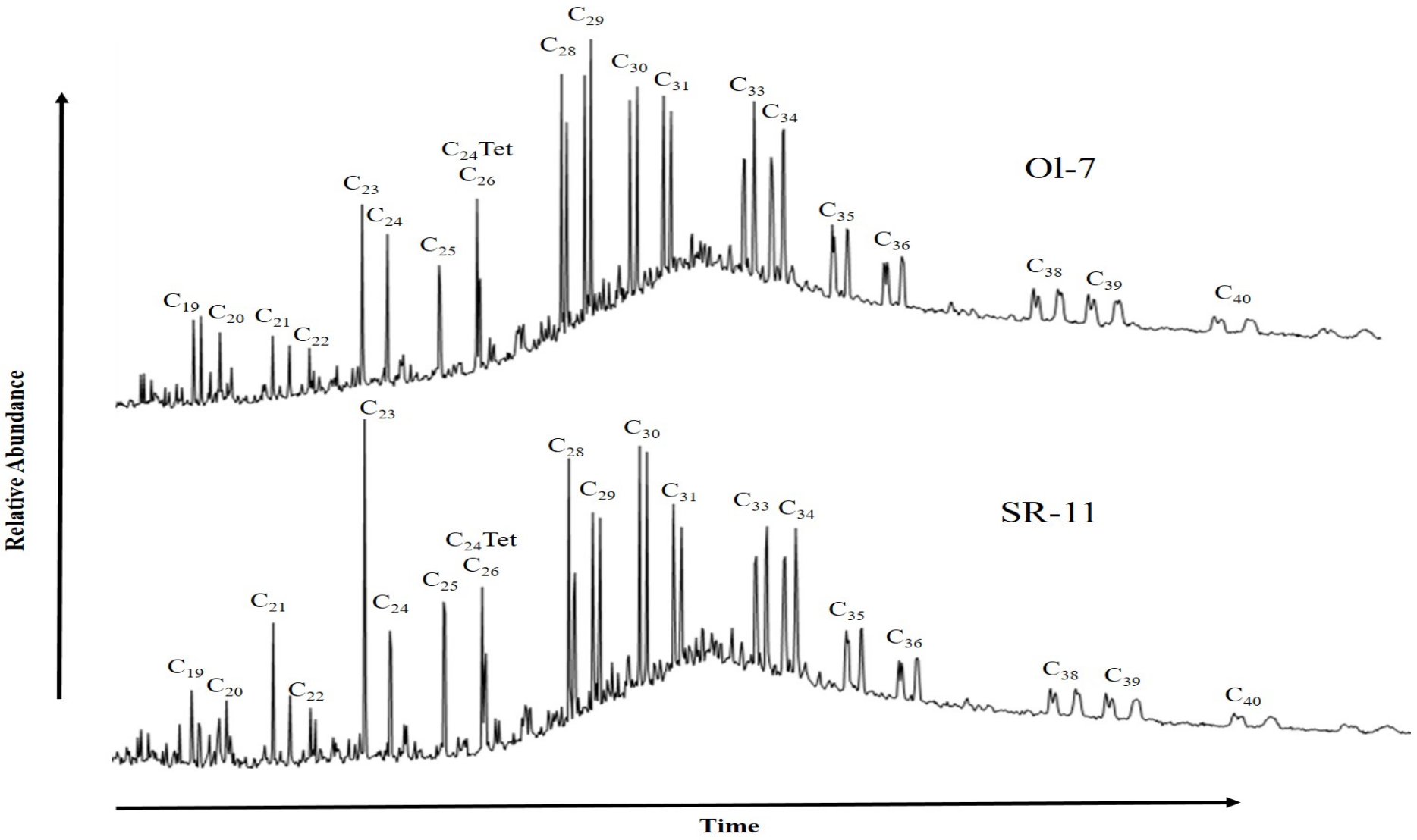


- Abundant arylisoprenoids and C_{40} carotenoids-Green sulfur bacteria
- No methylhopanes or 30-norhopanes
- Relatively low abundance of long chain isoprenoids
- Variable bisnorhopane concentrations
- Alkylsteranes are also present in many of the Woodford samples

Terpane Distributions in Goddard vs. Woodford Extracts



Terpane Distributions in SCOOP Oils and Goddard Extracts



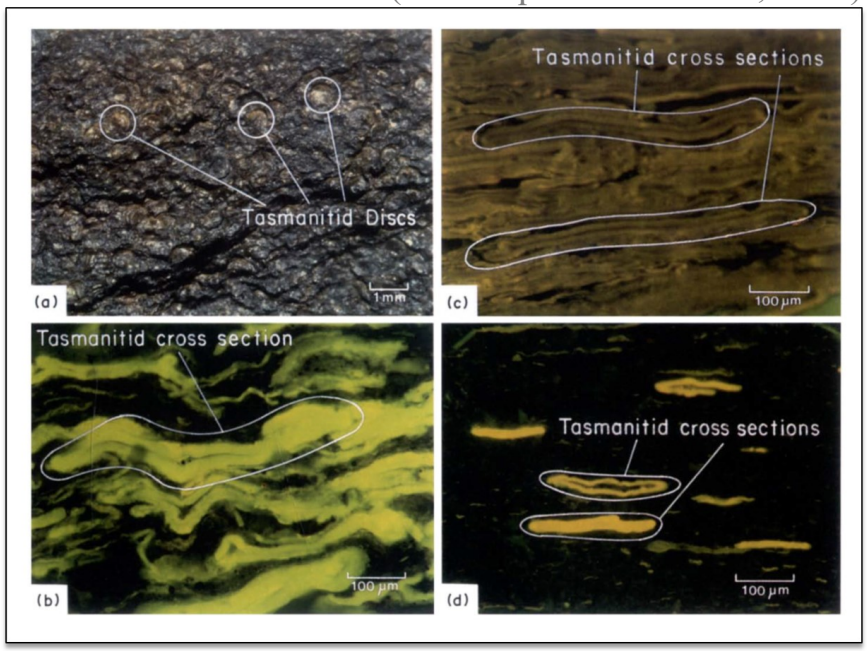
Tricyclic Terpanes

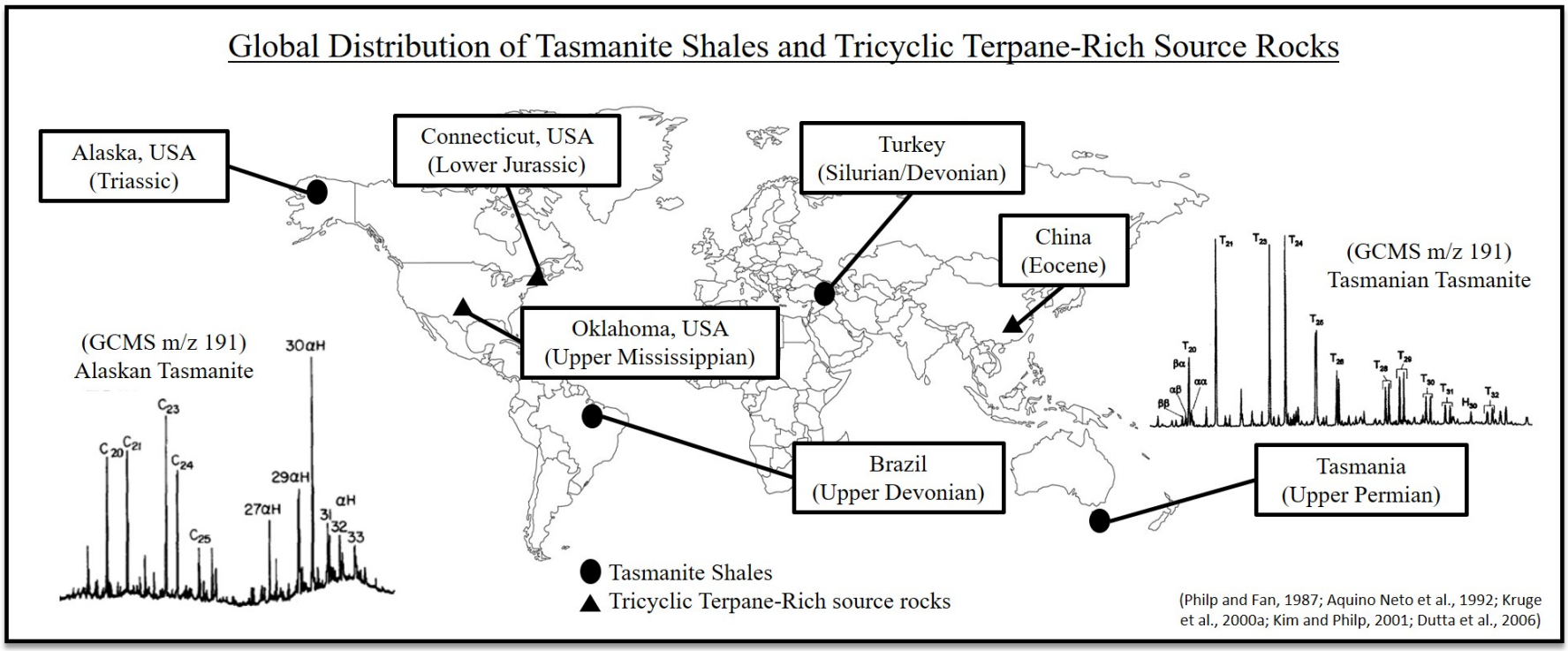
Precursors are debated

- Often attributed to *Tasmanite* algae
- *Tasmanite* shales are dominated by *Tasmanites*

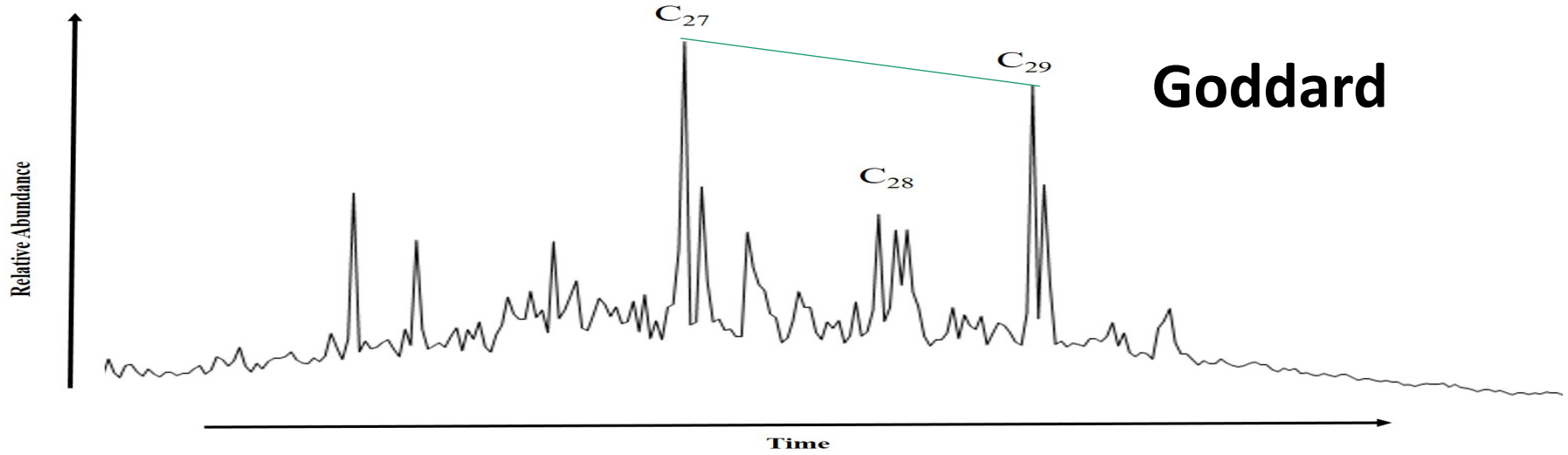
Common in most oils and source rocks

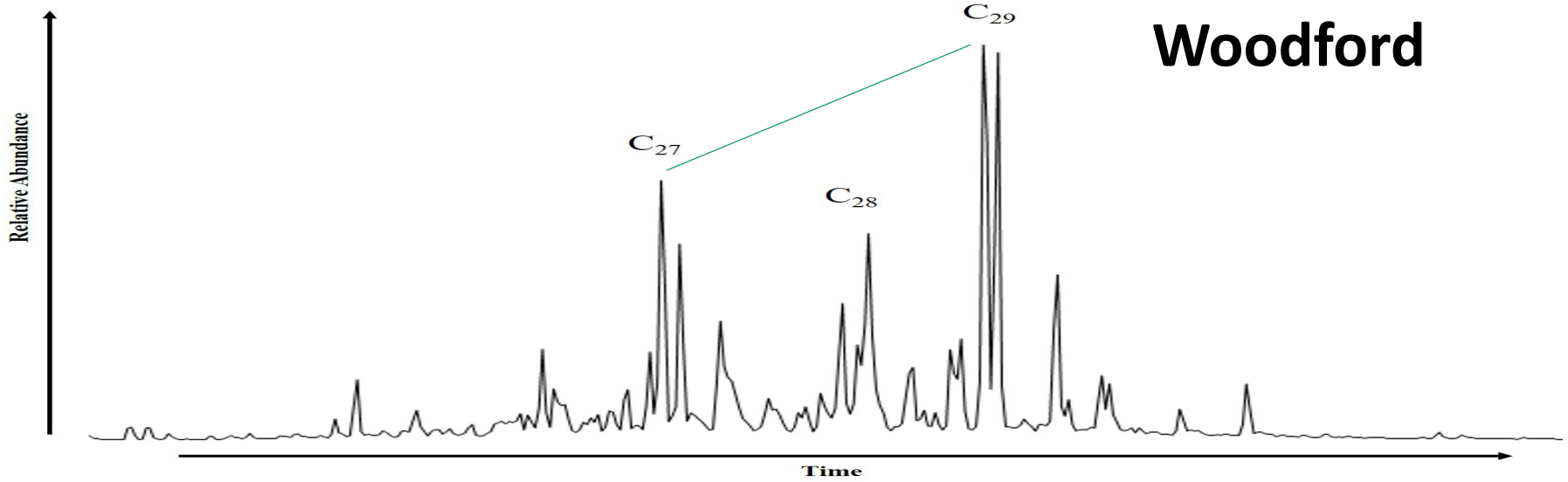
- Typically in low abundance relative to hopanes
- Abundance greater than hopanes is rare



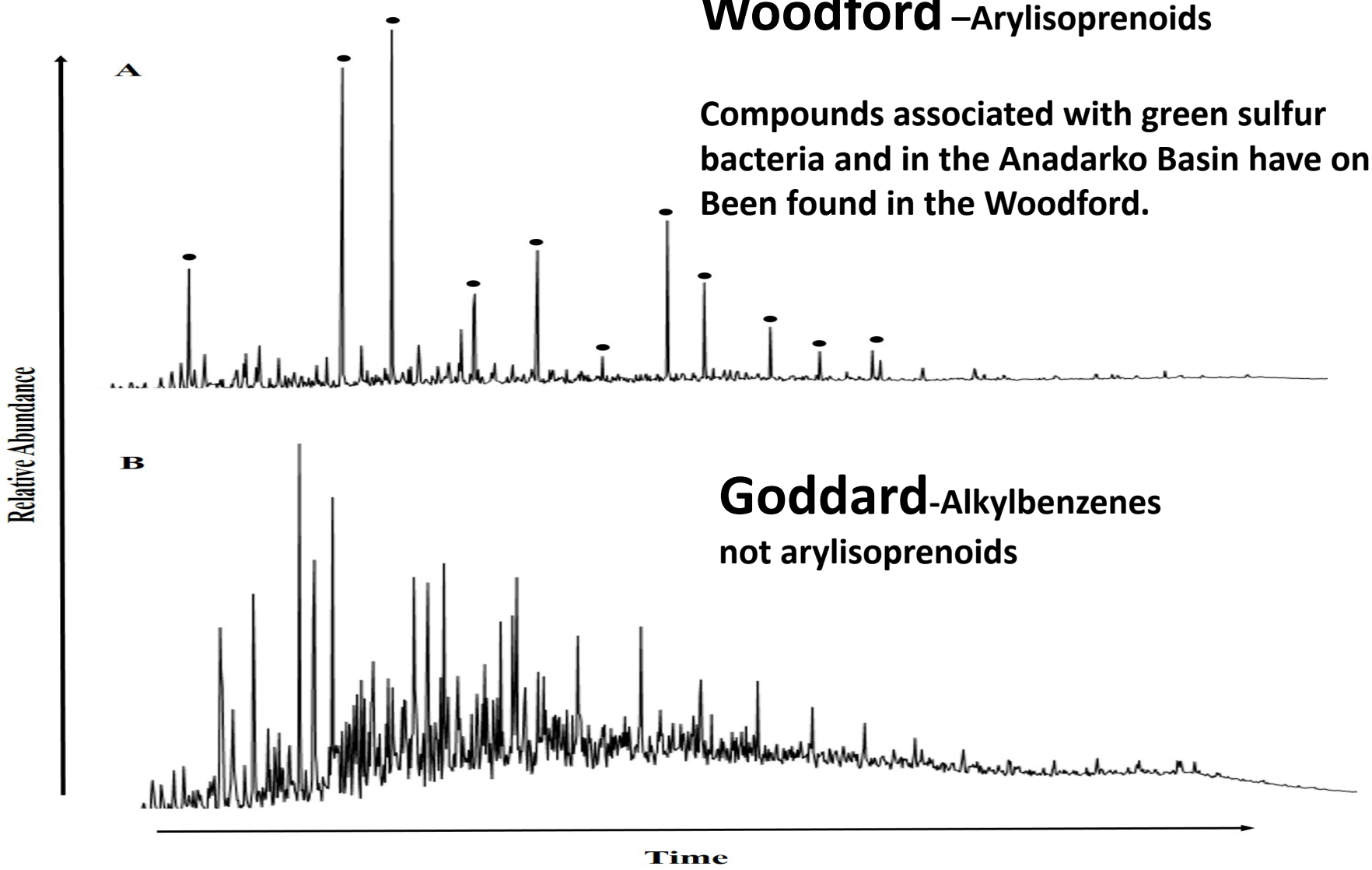


Steranes-Goddard vs. Woodford





Arylisoprenoids-Extracts

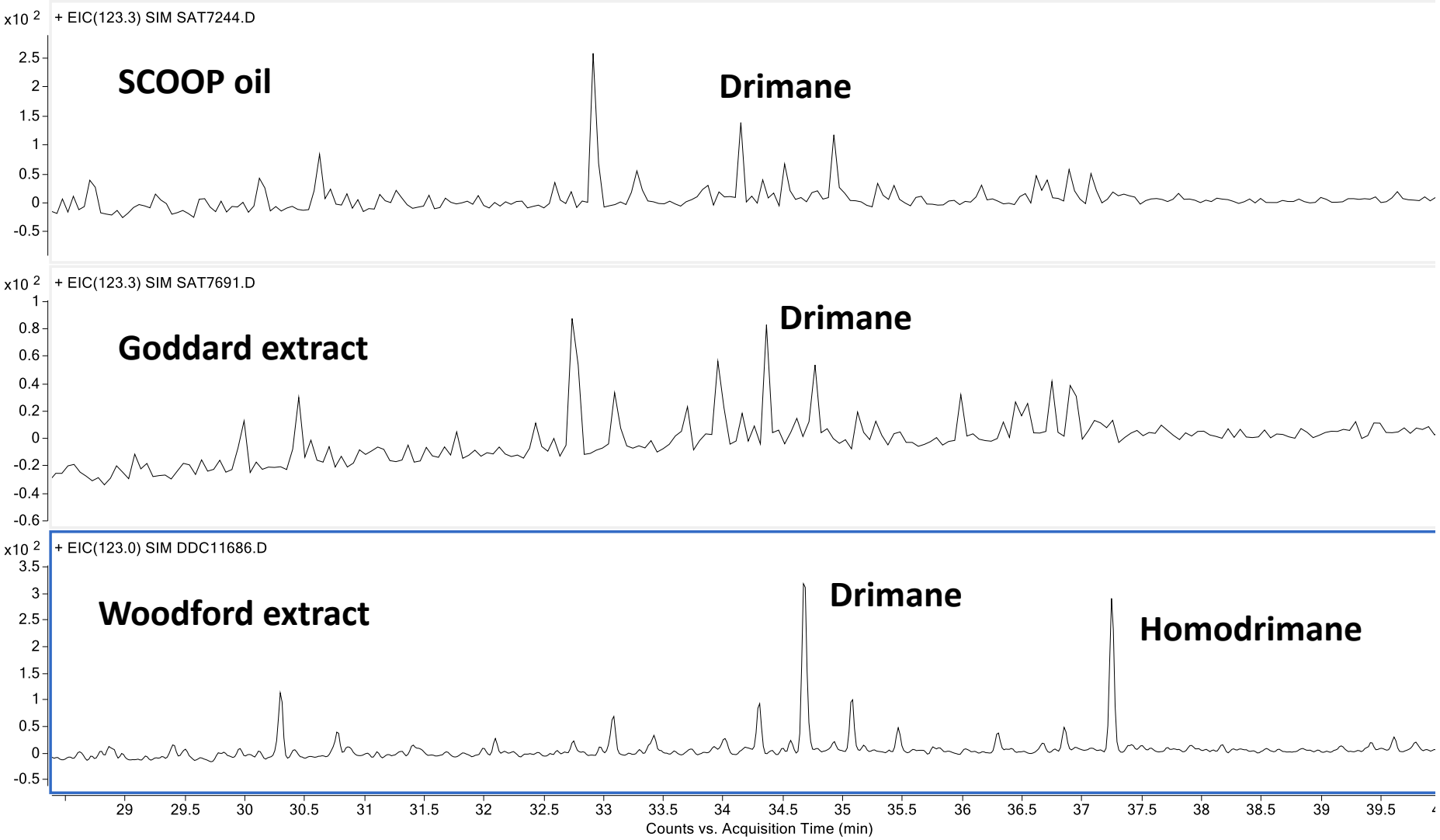


Woodford –Arylisoprenoids

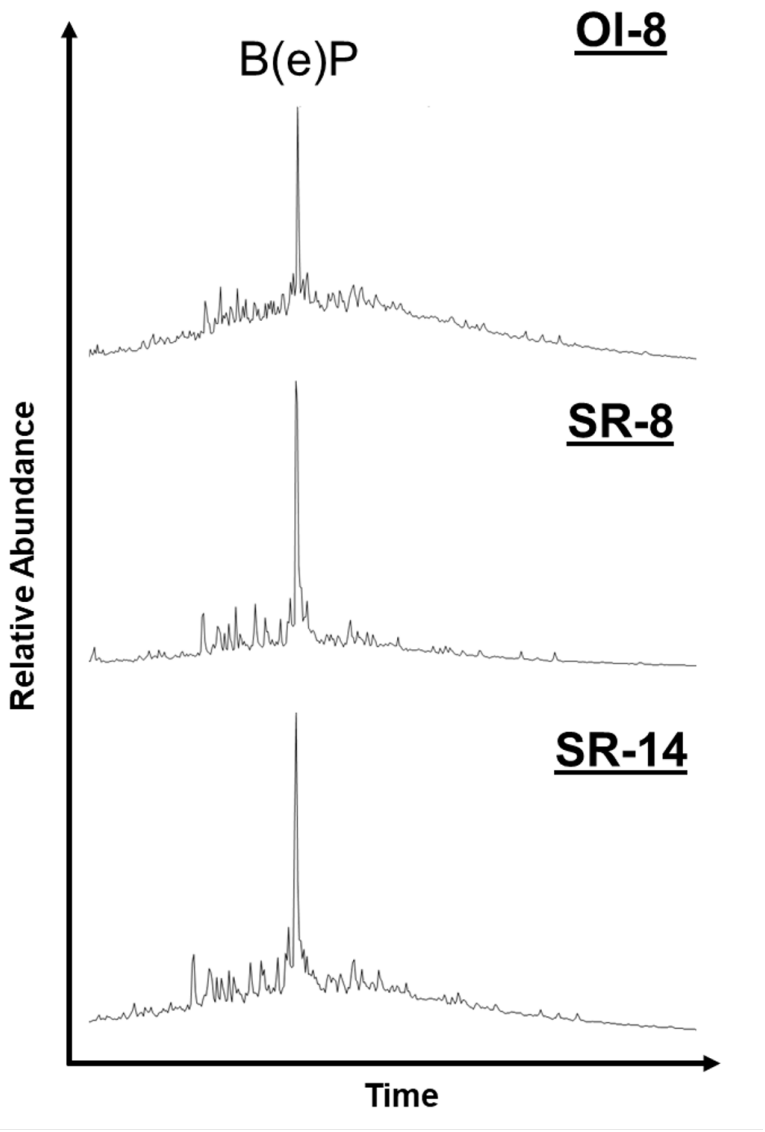
Compounds associated with green sulfur bacteria and in the Anadarko Basin have only Been found in the Woodford.

Goddard-Alkylbenzenes not arylisoprenoids

Sesquiterpanes



Evidence of Wildfires in the Goddard



- Benzo (e) pyrene is an indicator of combusted organic matter typically produced as a result of wildfires.
- Present in SCOOP oils and Goddard extracts.
- Combustion sources also supported by presence of the fusinite maceral shown earlier.

Summary

- Marine nature of Goddard organic matter confirmed by geochemical data.
- In the SCOOP area majority of samples examined have maturity values in the late oil window.
- TOC and HI values reflect this maturity level.
- Some of the crude oils showed possible evidence of earlier episodes of biodegradation followed by a second charge of a more mature condensate.
- The terpanes in the oils were dominated by a rather unique distribution of tricyclic terpanes that showed a very good correlation with the Goddard rock extracts.
- It would appear that in the SCOOP area the Goddard is a significant contributor to the source of the SCOOP oils.