The Implication of Maturation and Heat Flow Analysis for Conventional (Deepwater) and Unconventional (Shale Oil and Shale Gas) Petroleum Systems: Evolution Through the Last 50 Years*

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Other presentations from this session and posted on Search and Discovery are Article #80375 (2014) by Wallace Dow, Article #80385 (2014) by Robert Sterling and Anne Grau, and Article #80386 (2014) by Kenneth Peters.

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Abstract

The aspects of heat flow and maturation using vitrinite reflectance began in the 1930s and was utliized until the middle of 1960s for the sole purpose of evaluating coal. However, from the latter part of 1960s, maturation of dispersed organic matter (kerogen) changed our perspectives on the application of vitrinite reflectance to solve problems in the earth's diverse heat flow histories, particularly those associated with the petroleum basins. Although the concept of oil and gas generation in relation to heat flow and depth was well known worldwide in the 1960s, the windows concept (start and end points) of oil and gas generation in relation to vitrinite reflectance in source rocks presented by Wally Dow (1977) was/is unique. This work ultimately brought the petroleum geochemistry and petroleum system analysis into the forefront of earth science research. Vitrinite reflectance became a universal paleo-geothermometer for research on heat flow that can solve diverse problems for sedimentary basin evolution. The current research demonstrates how heat flow and maturation are related to chemical kinetics and hydrocarbon windows. The new concept can be related to the generation and migration of hydrocarbons in several selected basins-- source rocks from the deepwater (GOM, Grand Banks, and Scotian Basin) and unconventional (Bakken, Montney, Duvernay, Eagle Ford and Barnett) environments. The petroleum system parameters can be related to changes in tectonic elements (salt, erosion, thrust, and stress), mineralogical variations, igneous associations, and organic and sedimentary environments. This new concept of maturity in relation to chemical kinetics and stress can provide a basic framework for improving predictions about hydrocarbon saturation in the "hot spots" and prediction of "oil' versus "gas," using multiphase maturation windows.

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The Implication of Maturation and Heat Flow Analysis for Conventional (Deepwater) and Unconventional (Shale Oil & Shale Gas) Petroleum Systems: Evolution Through the Last 50 Years

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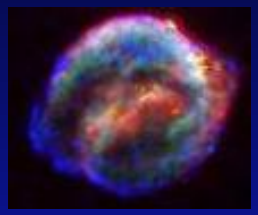
Maturity is a Constant Event and Changes through Time and Space
Progression of Maturity is Universal and Irreversible

Advancement of Maturity within the Stars in the Universe

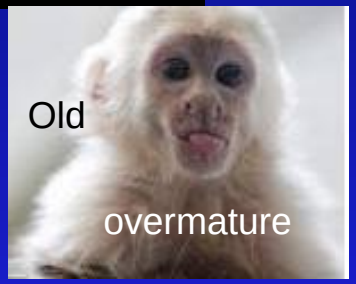
young immature planet

mature adult planet



overmature or old planet or supernova

Progression of Maturity within Larger Animal on Earth

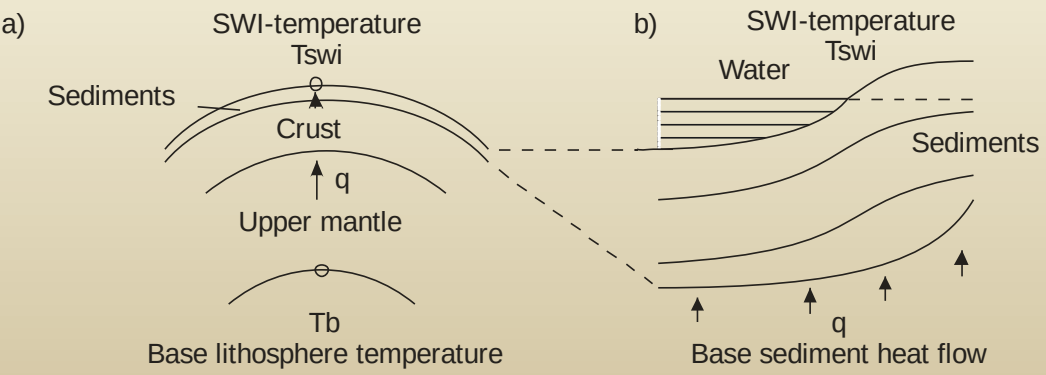


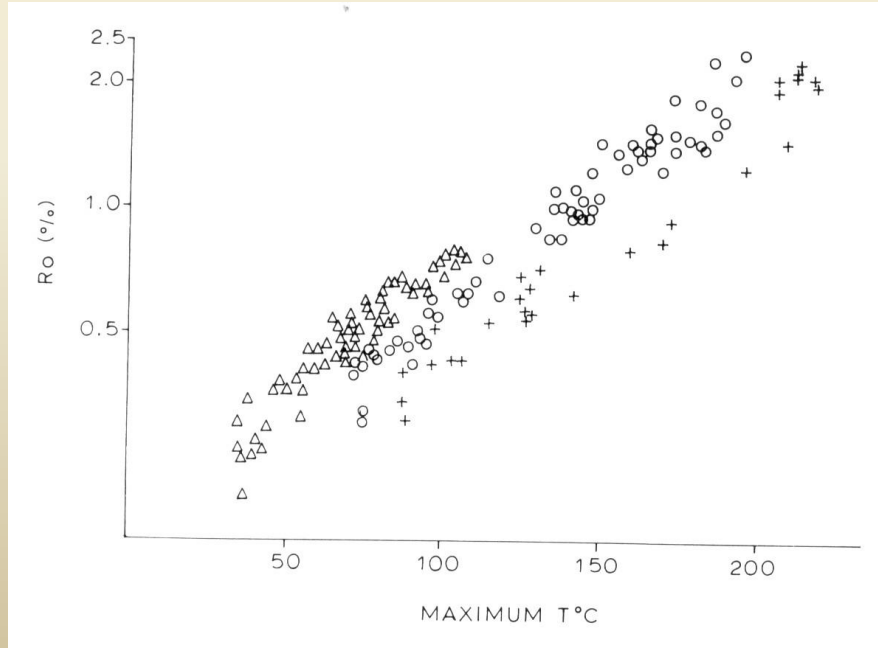
Progression of Maturity within Phyto & Zooclasts on Earth

- Historical Review of Vitrinite Reflectance
- Wally Dow's Contribution to Maturity and HC Generation Time Line

What is the Best Parameter for Maturity?

Vitrinite Reflectance is the main maturation parameter which is mostly temperature and time dependent but partially dependent on pressure. It is used for precise evaluation of the limits of oil and gas boundaries in both conventionally and unconventionally forming source rocks





History of Maturity or Vitrinite Reflectance Measurement

1. Started in 1932 by Hoffmann and Jenker in 1932 Germany using Berek Photometer for various Coal Rank determination using an Incident Light Microscope

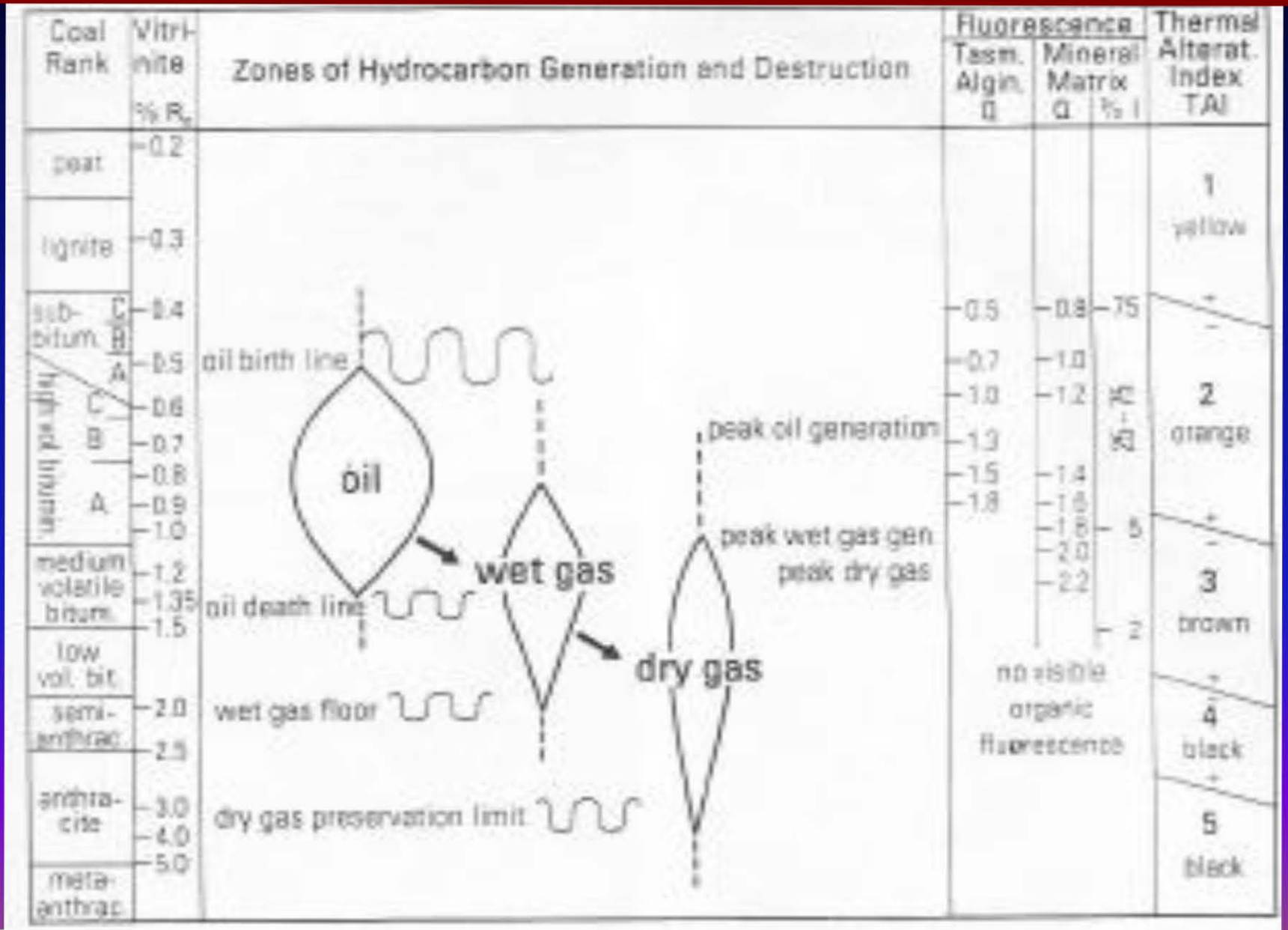
2. Seyler 1943 in United Kingdom started the vitrinite and other maceral reflectance using immersion oil and Incident Light Microscope. He also identified first various types of vitrinite reflectance and stepwise maturity increase with advanced coal rank

3. However, in the 1960s, Karweil and Marlies Teichmuller, identified various issues of vitrinite reflectance and its relation to : (a) heat flow and temperature (b) Possible relation with the oil and gas generation

4. However the Spore Coloration and its relattion to Oil & and Gas stages was documented in the 1960s and early 1970s (Combaz,1964, Gutjahr, 1966, Staplin,1969, Burgess 1974).

5. Wally Dow (1974, 1977) and Prof. Dietrich Welte and his Research Group (1974-1979) introduced the implication of vitrinite reflectance and oil and gas boundaries. Wally Dow (1977) introduced the term “oil or gas birth and death lines or oil and gas preservation limits” based on % Ro

Implication of Wally Dow (1977) contribution on %Ro and modern HC Windows Concept



Vitrinite Reflectance in Conventional and Unconventional Oil & Gas Exploration

- **Short Understanding about VRo Measurement**
- **Selected Use of VRo in Unconventional Resources Evaluation**
- **Selected Use of VRo in Conventional Resources Evaluation (especially deepwater)**
- **Correlation of Vitrinite with Other Parameters**

Vitrinite Reflectance in Conventional and Unconventional Oil & Gas Exploration

- **Short Understanding about VRo Measurement**

Vitrinite Reflectance Measurement uses incident light microscopy, an oil immersion 40X objective. Reflectance is measured at 546 nm and standardized using at least two reflectance standards. Two types of vitrinite reflectance are measured; a) random and b) maximim/minimum reflectance are usually measured. The following equation shows how the vitrinite reflectance measured in immersion oil and is calibrated with a standard

$$R_o = \frac{(\mu - \mu_o)^2 + \mu k^2}{(\mu + \mu_o)^2 + \mu^2 k_o^2} \qquad (1)$$

where:

μ, μ_o = refractive index of vitrinite and immersion oil, respectively;
k, k_o = absorption index of vitrinite and immersion oil, respectively.

$$\%\ R_o\ (\text{standard}) = \frac{(\mu_{\text{standard}} - \mu_{\text{oil}})^2}{(\mu_{\text{standard}} + \mu_{\text{oil}})^2} \times 100 \qquad (2)$$

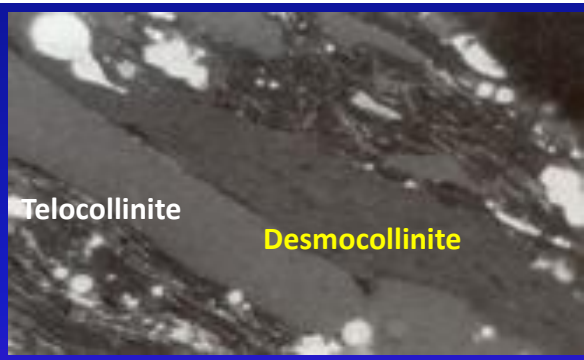
Vitrinite Group Nomenclature Documentation on Vitrinite Macerals and What we Measure?

We measure only
First Cycle Vitrinite Grains

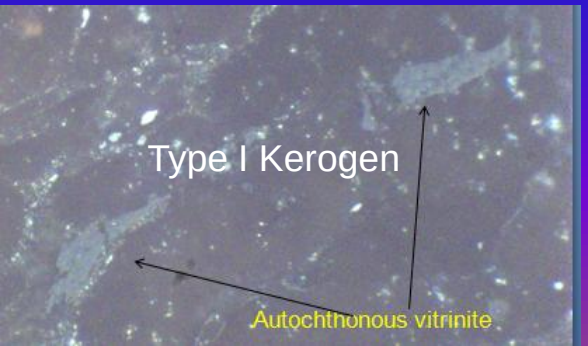
VITRINITE GROUP (ICCP, 1982)		VITRINITE GROUP (ICCP, 1994)	
Maceral	Submaceral	Maceral	Maceral subgroup
Telinite	Telinite 1 Telinite 2	Telinite	Telovitrinite
Collinite	Telocollinite	Collotelinite	
	Desmocollinite	Collodetrinite	Detrovitrinite
		Vitrodetrinite	
	Corpocollinite	Corpogelinite	Gelovitrinite
	Gelocollinite	Gelinite	
Vitrodetrinite[1]			

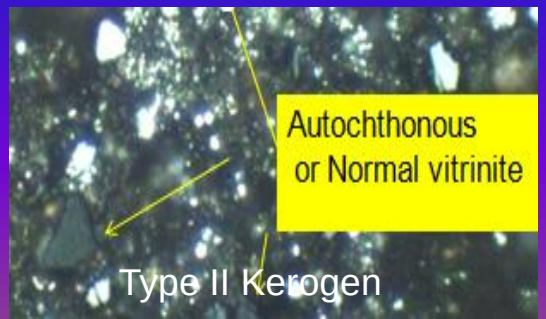
[1]Vitrodetrinite is incorporated in the detrovitrinite subgroup (ICCP, 1994)

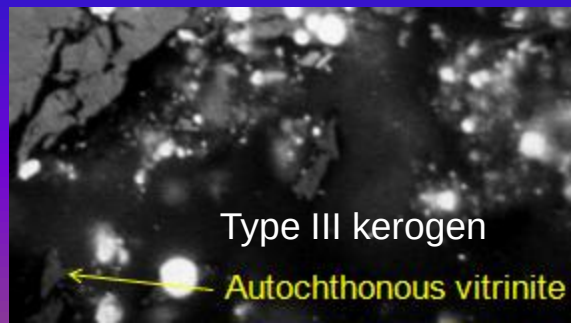
Vitrinite in Coal



Vitrinite in DOM Shale

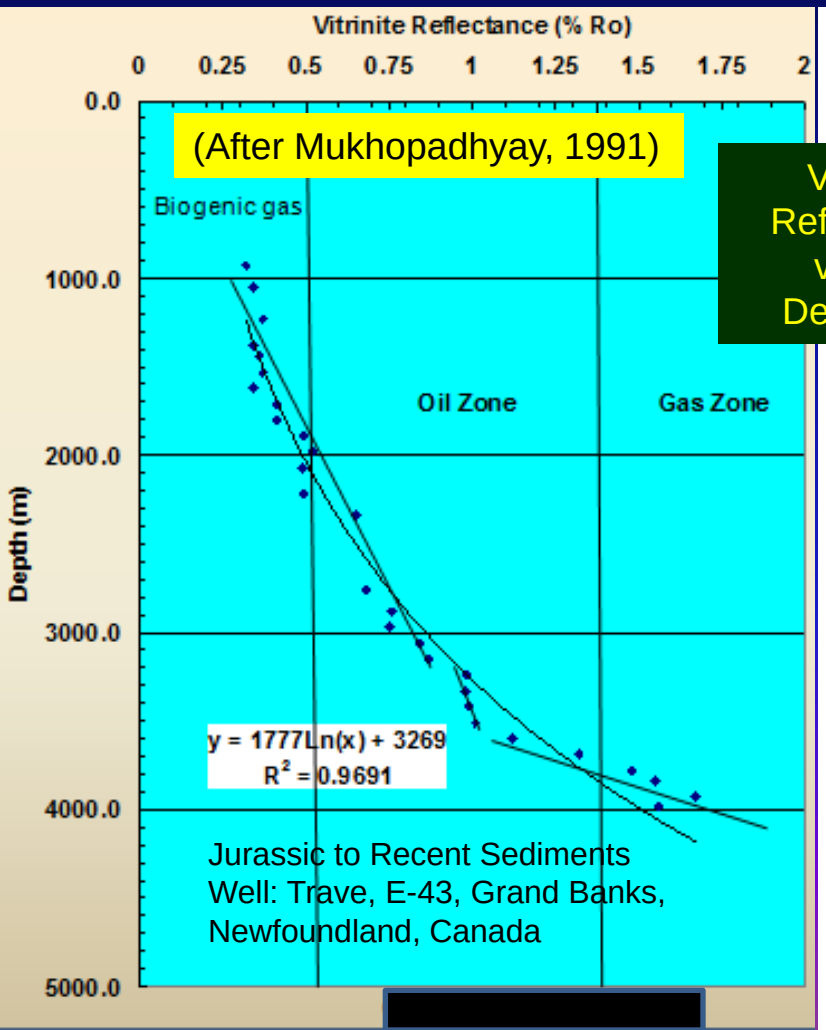




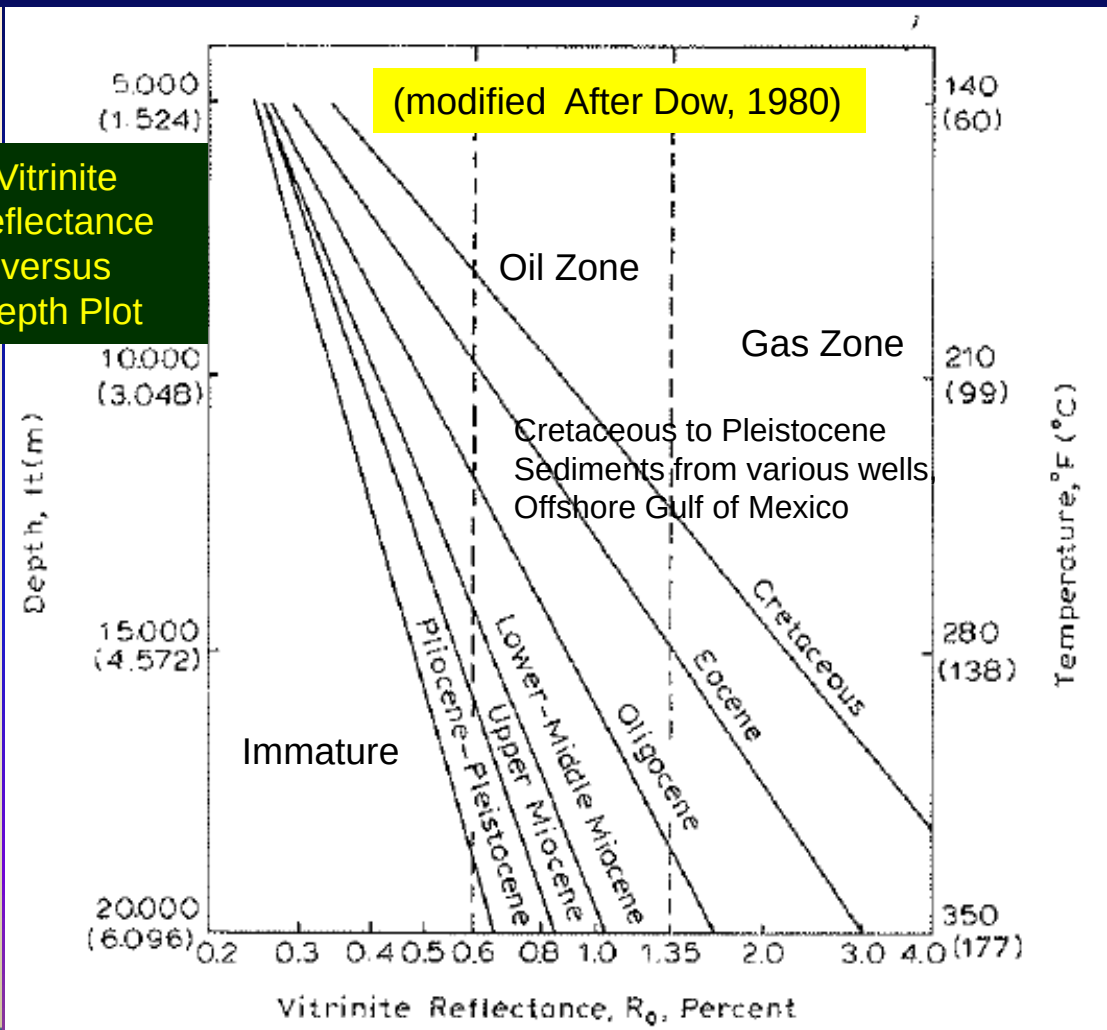


Vitrinite Reflectance Plots (Sedimentary Basins)

Two Types of Reflectance versus Depth Plots: Log (Dow, 1977) and non-log (Mukhopadhyay, 1980) plots. Each type has its advantages and disadvantages



Vitrinite Reflectance versus Depth Plot



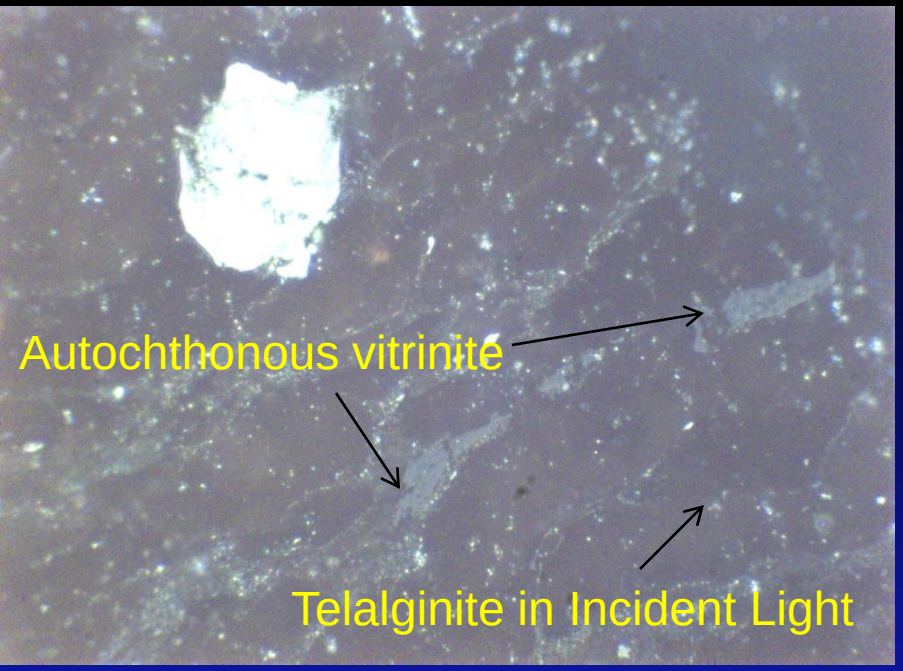
Vitrinite Reflectance in Unconventional Oil & Gas Exploration

- **Vitrinite Reflectance Anomalies: Selected Issues and Their Possible Calibration**
- **Vitrinite Ro and Bitumen Reflectance and their use**
- **Kinetics and Vitrinite Reflectance: Early Oil or Late Oil**
- **Maturation and Development of Secondary Porosity In Shale**

Vitrinite Reflectance Anomalies: Selected Issues and Their Possible Calibration

Effect of Various Issues

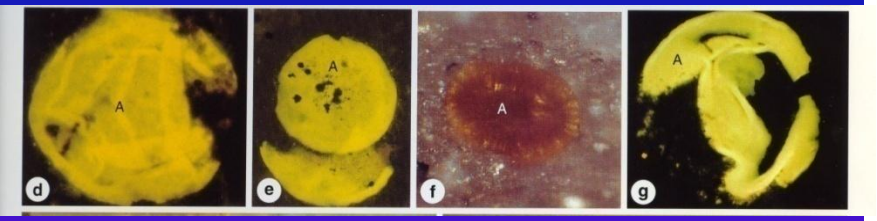
- **Lithology and Bitumen: Suppression of %Ro**
- **Overpressure: Retardation**
- **Major Thrust and Fault Systems: Anomalous vitrinite reflectance**



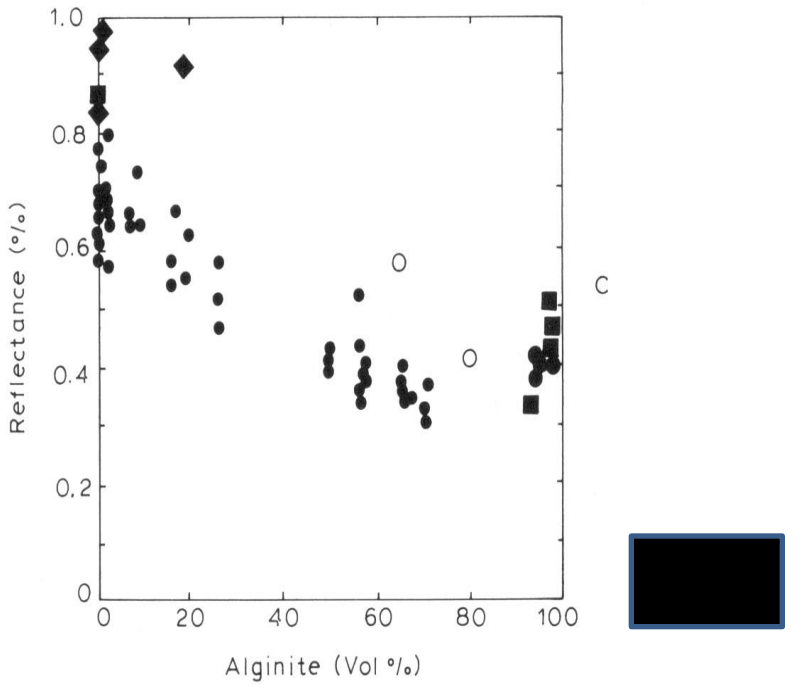
Suppression of Vitrinite Ro

Organic Facies-Bitumen

Lacustrine Type I Oil shale,
NSW, Australia

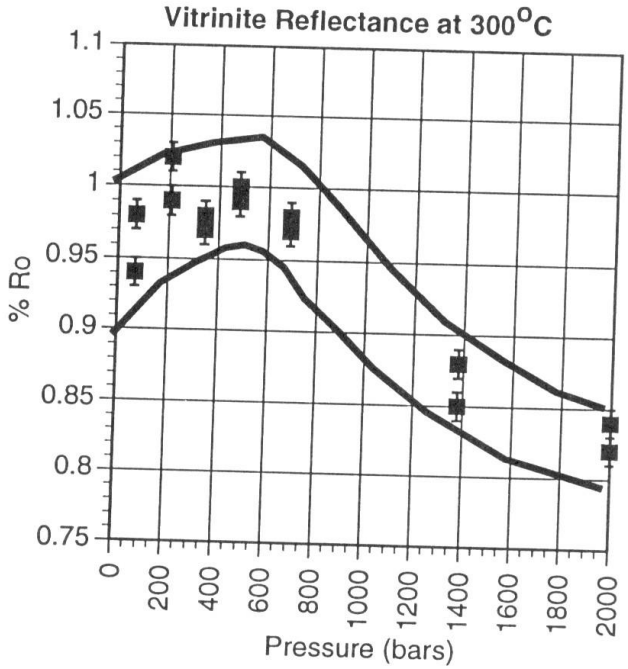


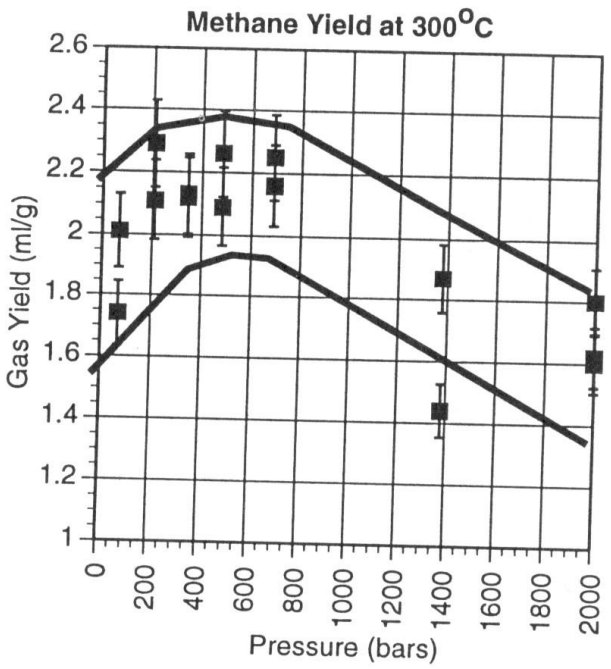
Marine Type I –II Devonian Shale,
WCSB, Alberta, Canada

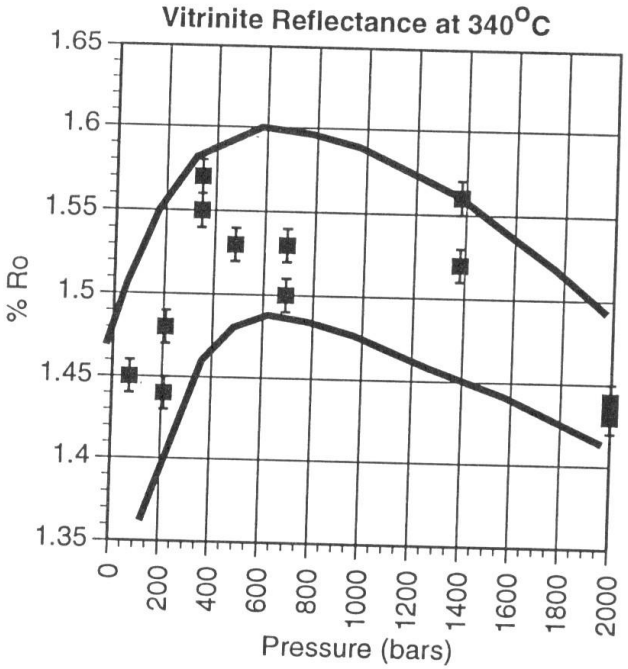


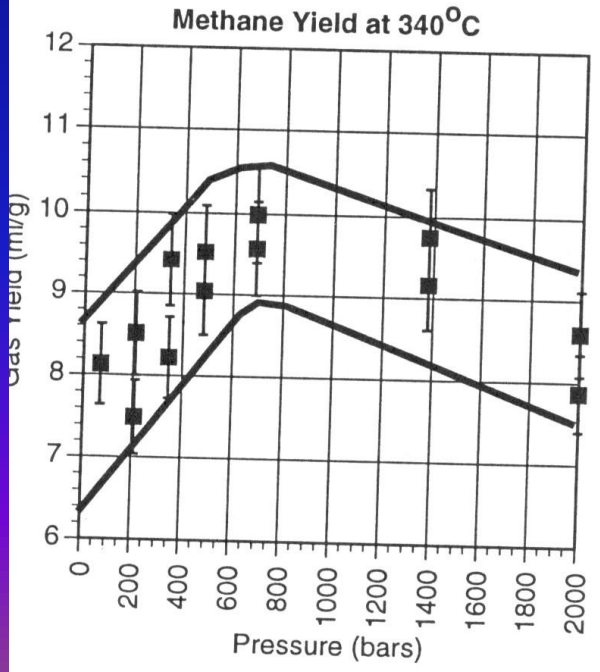
Experimental Documentation Of Pressure Retardation of Maturity & Associated methane generation

(After Hill et al., 1994)

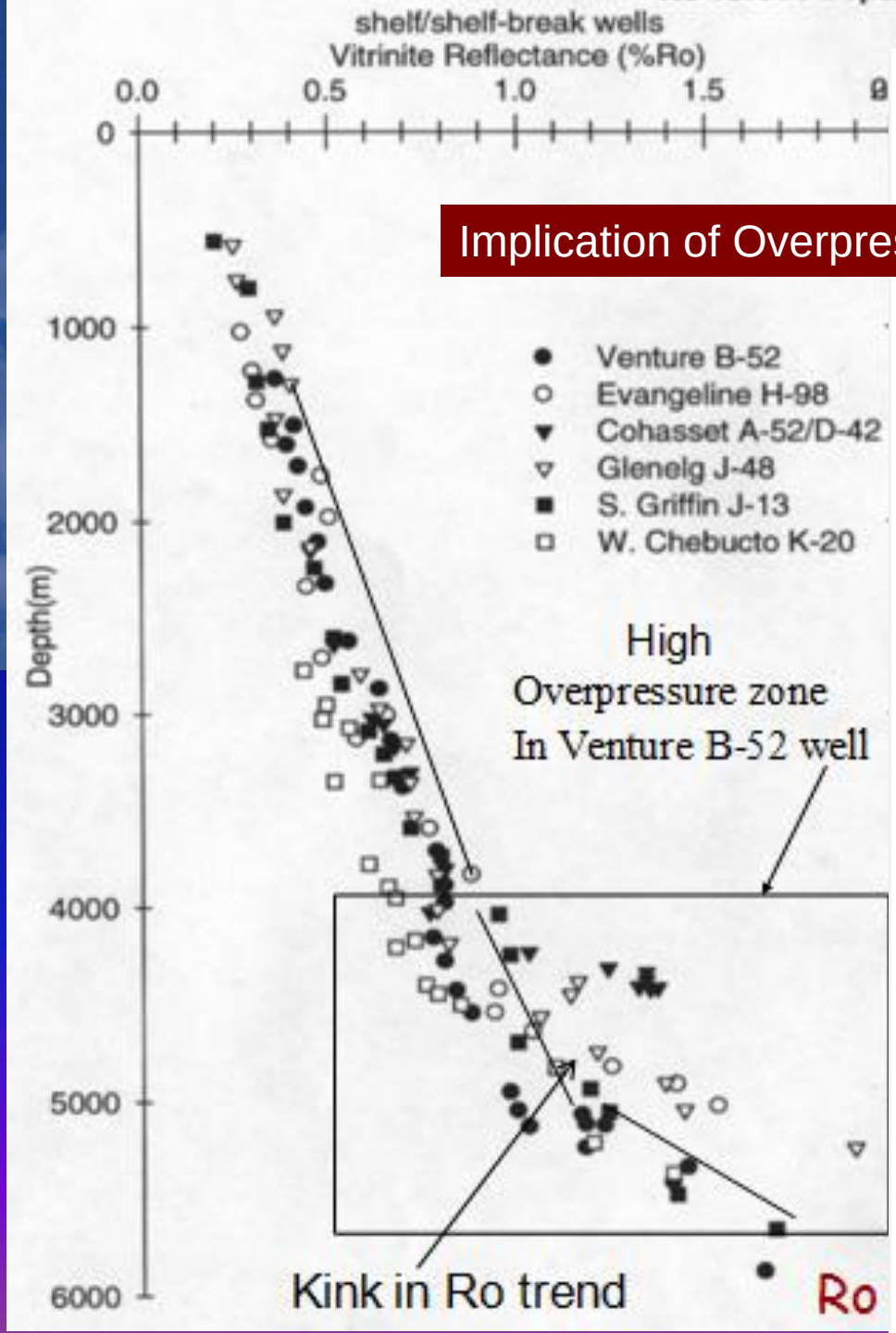


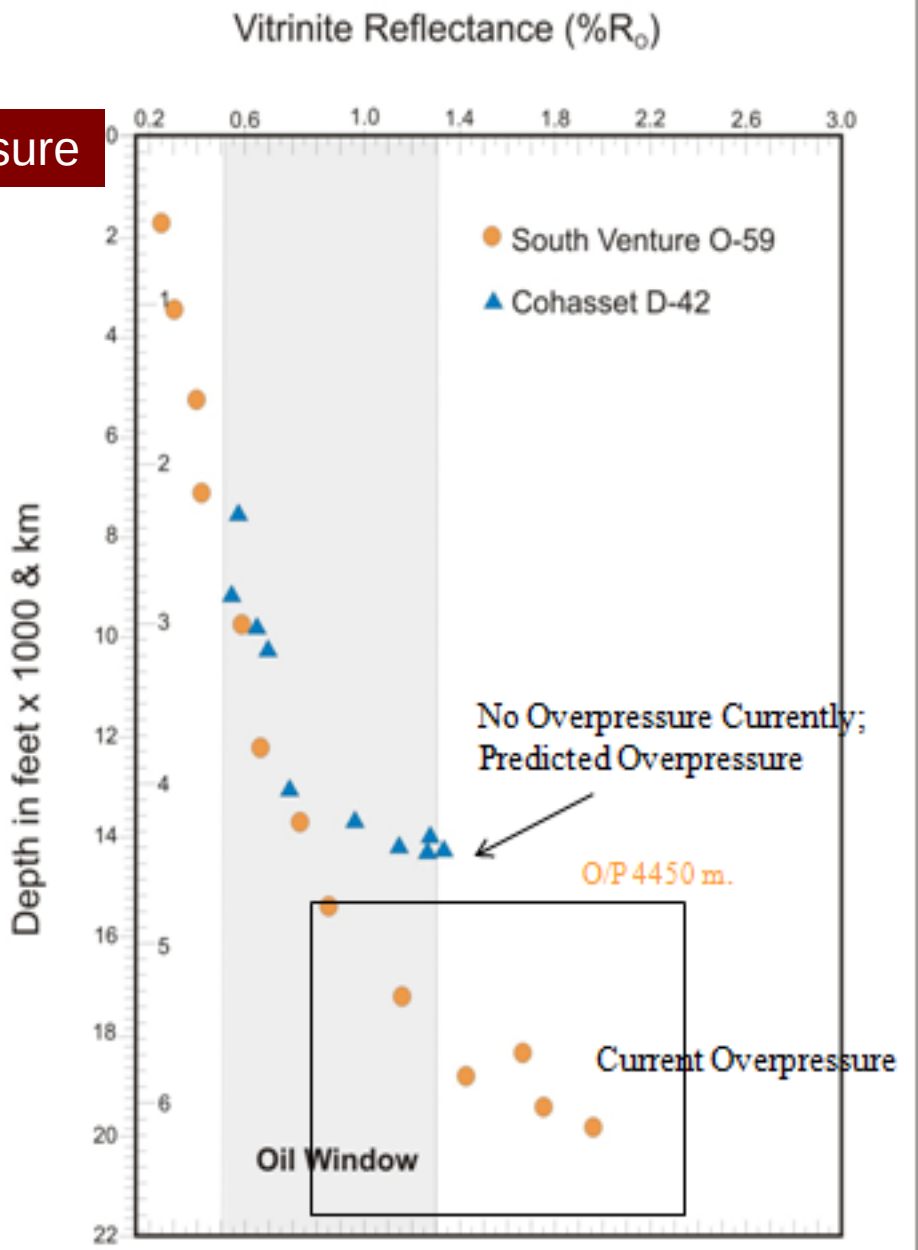






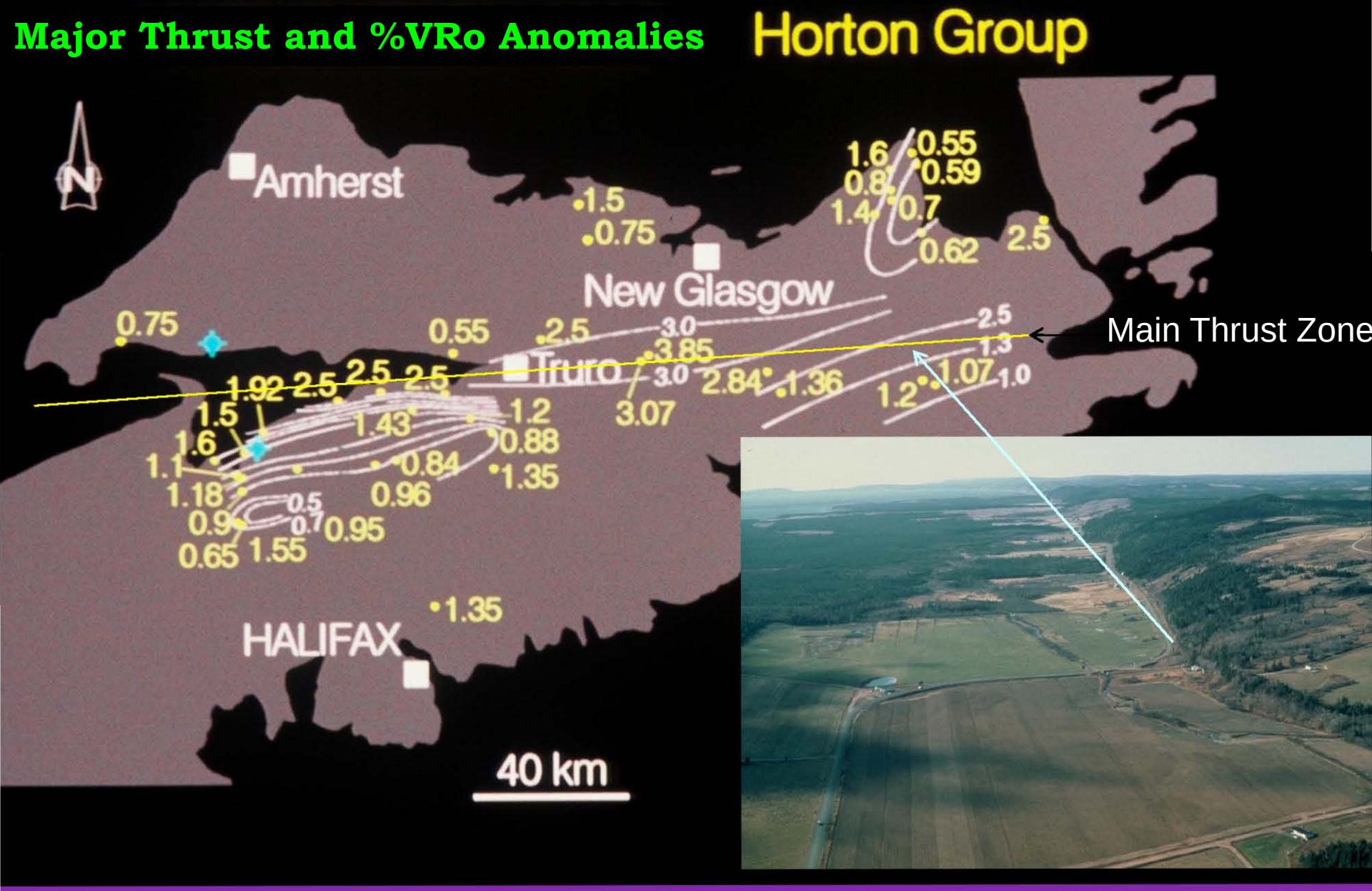
Implication of Overpressure





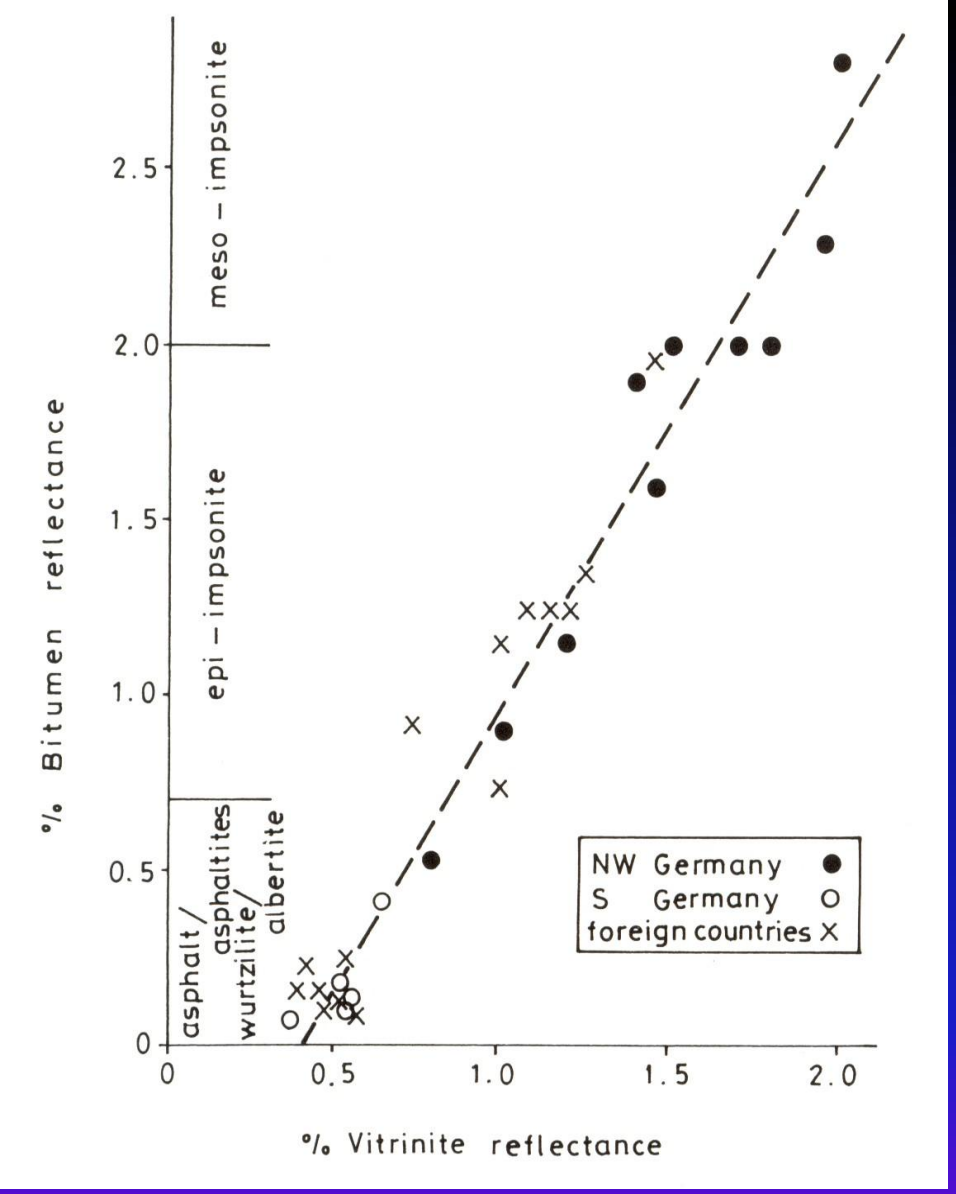
Onshore Nova Scotia

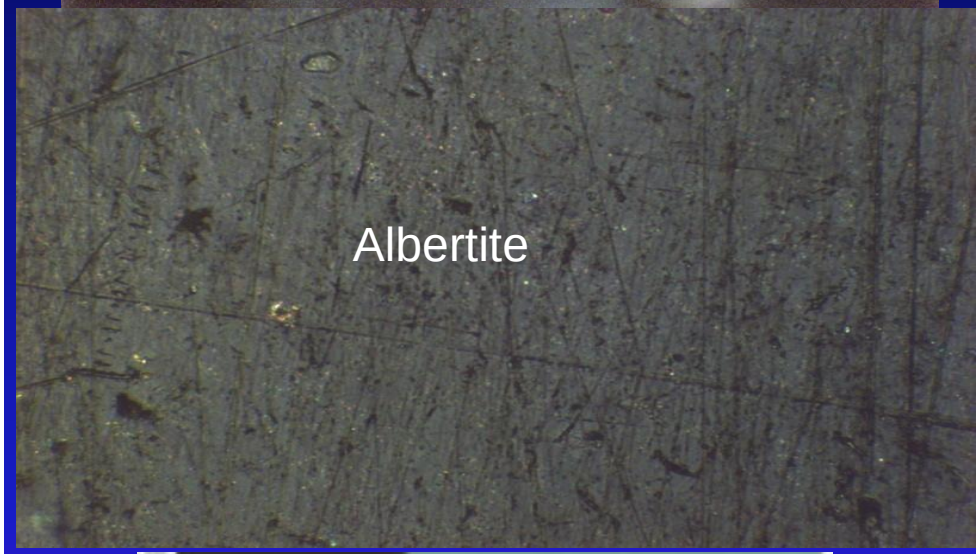
Major Thrust and %VRo Anomalies



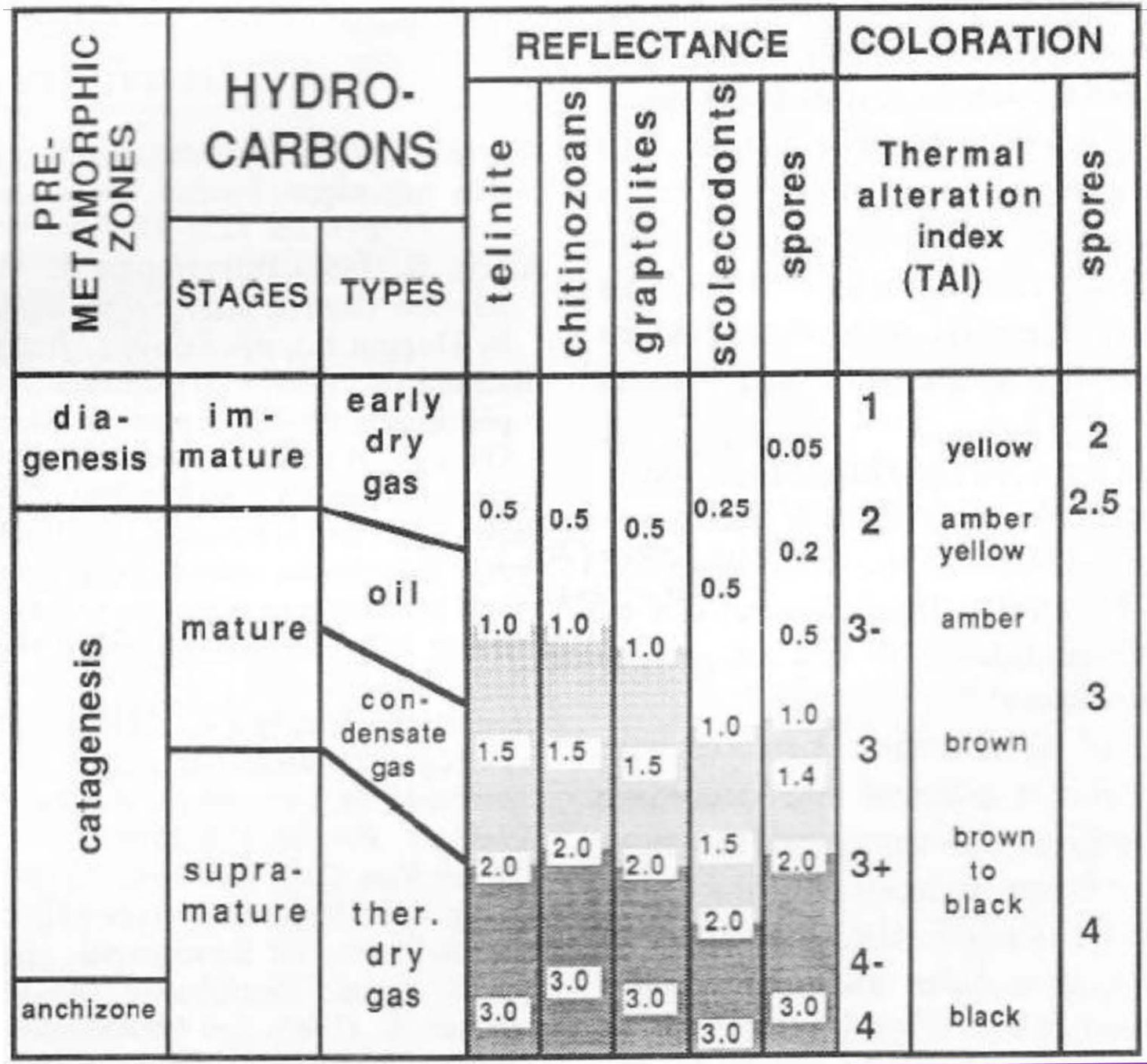
Vitrinite Reflectance in Unconventional Oil & Gas Exploration

- **Correlation of Vitrinite, Bitumen, Graptolite, and Zooclast Reflectance and their Importance in Lower Paleozoic Source Rocks**





Correlation of Vitrinite Reflectance and Solid Bitumen Reflectance (after Jacob, 1985)



Correlation of Various Parameters In Shale or Limestone In Lower Paleozoic Source Rocks (Cambrian, Ordovician, Silurian)

Courtesy, Bertrand et al., 1996

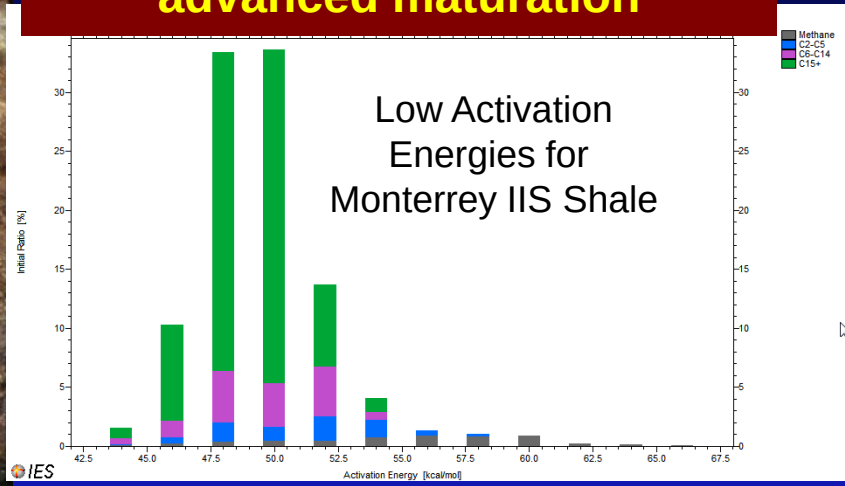
Vitrinite Reflectance in Unconventional Oil & Gas Exploration

- **Kinetics and Vitrinite Reflectance: Early Oil or Late Oil**

Monterrey Type IIS SR is expelling oil,
Carpentaria Beach, California

Ro: 0.30%,
Deepwater Monterrey Kerogen
Type IIS Source Rock

Organic Petrologically, the Timing of Oil & Gas Generation can also be visualized comparing the changes in Kerogen Network during the advanced maturation



The bondage between minerals and amorphous organic may show the catalytic effect of various elements that could reduce the temperature effect of Cracking Histories for the Timing of Oil and Generation. Early Oil Generation could be microscopically visible

Vitrinite Reflectance in Unconventional Oil & Gas Exploration

- **Maturation and Development of Secondary Porosity In Shale**

Organic Pores & Maturation (micron and nanometer sizes)

Primary Pores
(micron sizes)
Non-Maturity Pores
(e.g., Fusinite,
Sclerotinite,
Alginite and Amorphinite)

Secondary Pores
(both micron and
nanometer sizes)
Maturity Induced Pores
(e.g., bitumen dissolution,
Alginite Structural Changes
Liptinite Structural Changes
Density Changes between
Macerals
Neoformed granular bitumen)

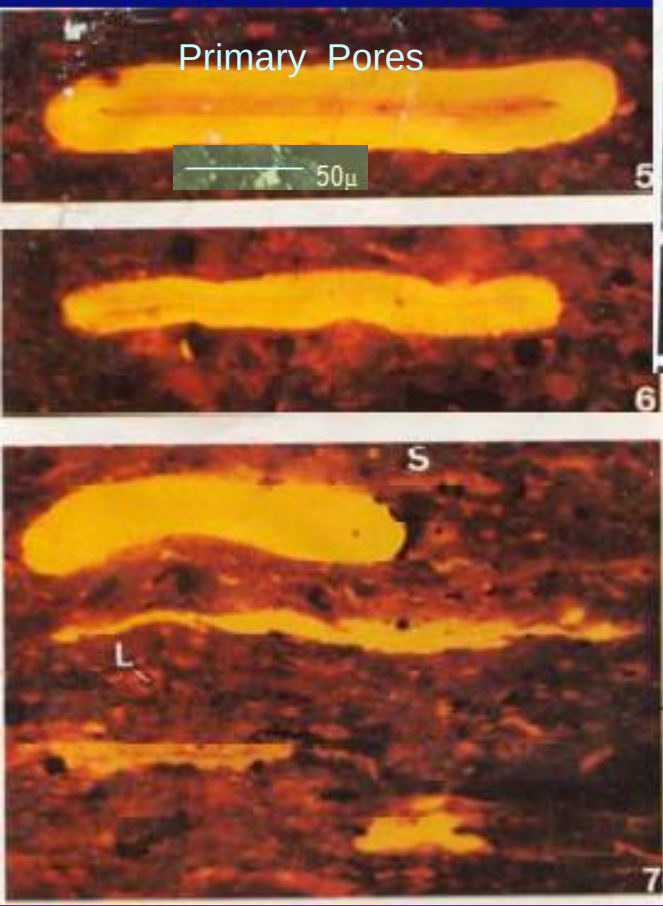
Transformation of tasmanales algae (Telalginite) in three different maturation stages: Type I Kerogen

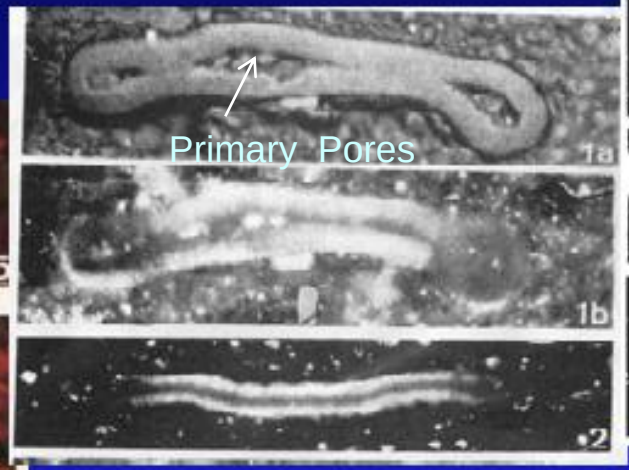
(Reflected white & Blue Light)

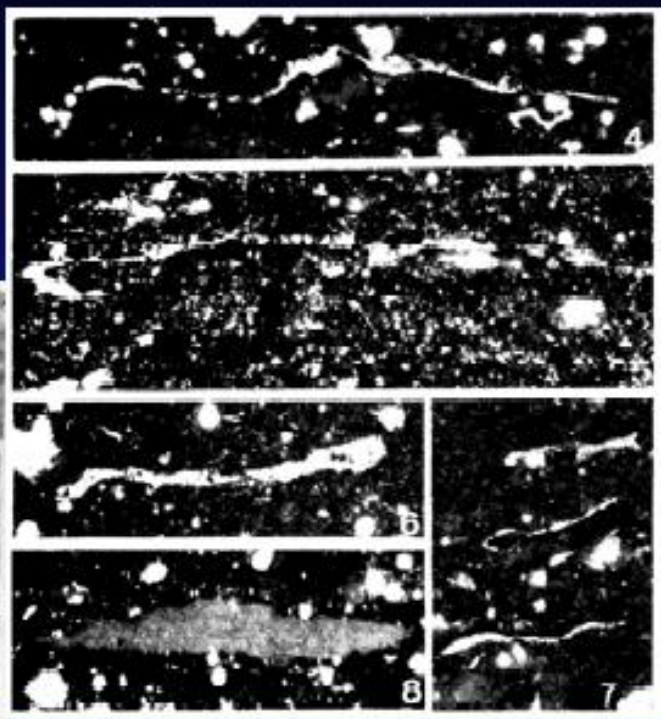
Stage 1 (0.6% -0.9 Ro)

Stage 2 (1.3-1.6% Ro)

Stage 3 (1.8 to 3.0% Ro)

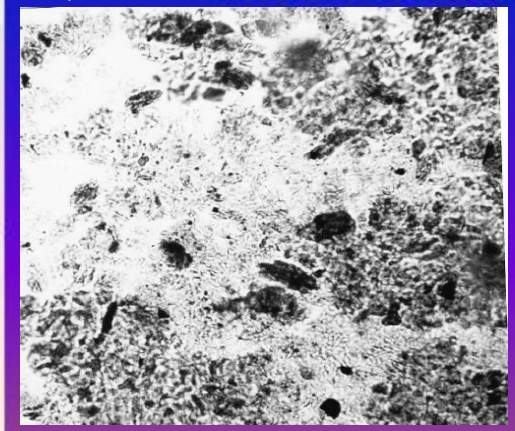






Wet Gas Zone

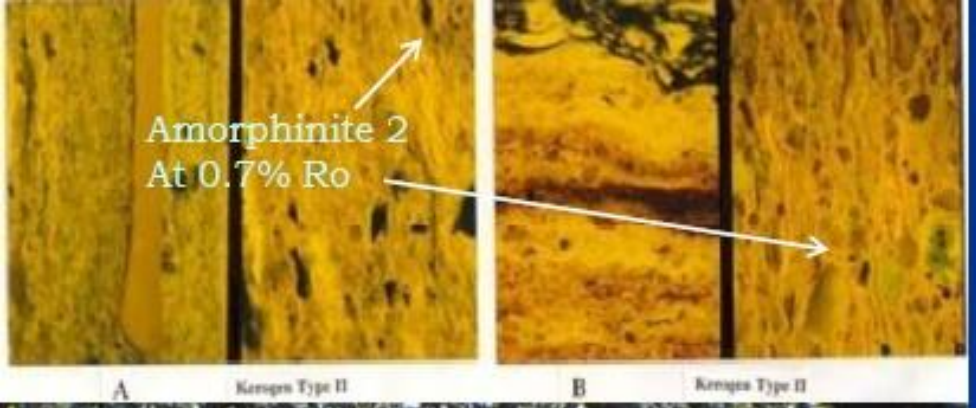
Dry Gas Zone

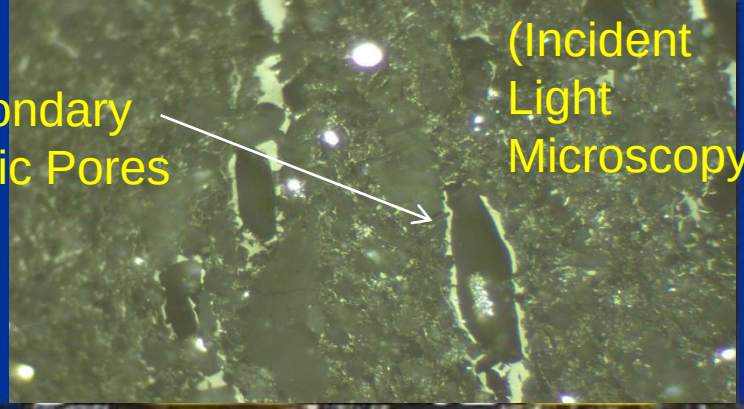


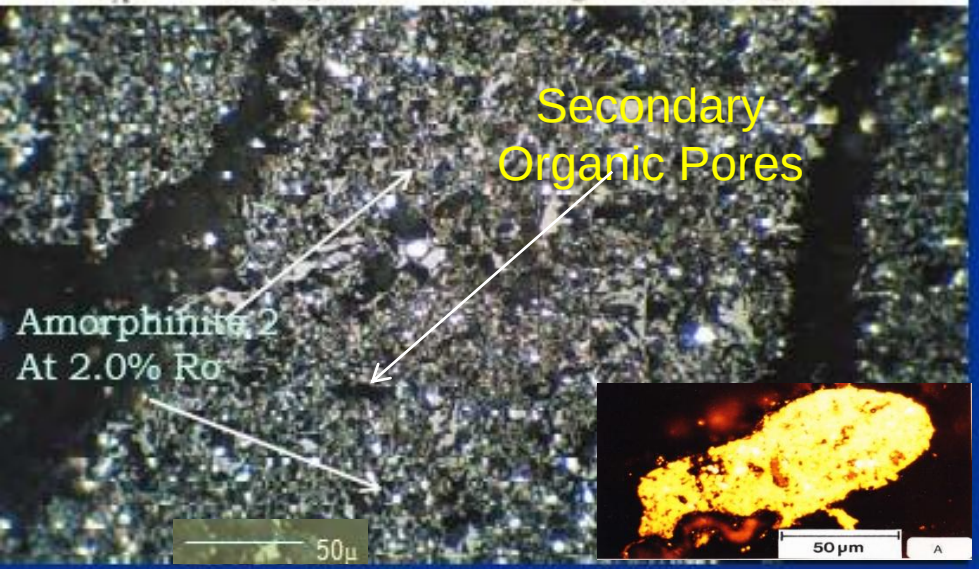
Type I Kerogen

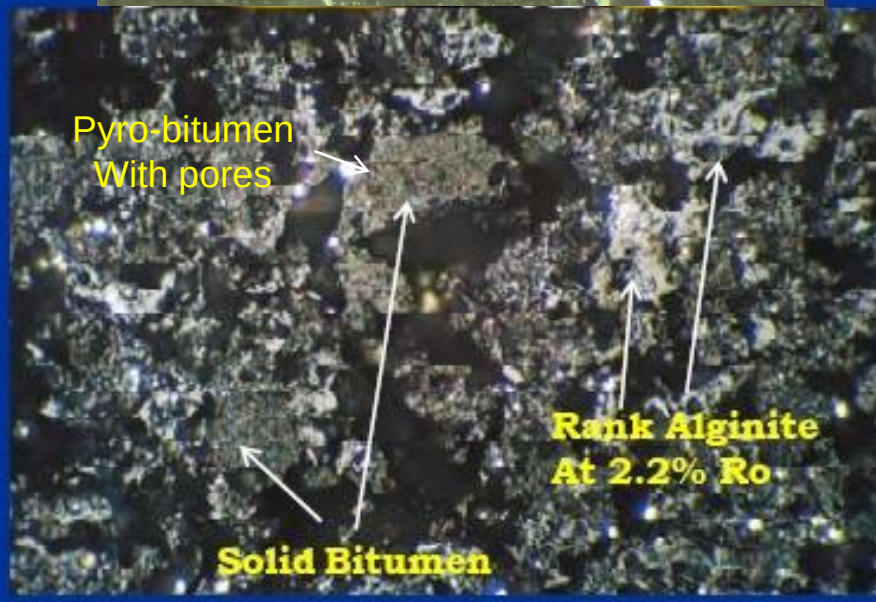
(Transmitted white Light)

(after Mukhopadhyay et al., 2013)









Type II Amorphous Marine Kerogen and their Maturation Transformation

The top left figure depicts the Type II amorphous kerogen (Amorphinite II) in immature stage with golden yellow fluorescence which became non-fluorescent and shows various types of organic pore development

(after Mukhopadhyay et al., 2013)

Biogenic Gas, Shale Oil, Condensate and Shale Gas

Are Nothing But a Maturation Transition of Various Oil- /Gas-Prone Organic facies

Same Source Rock can Generate Four Sequences of Hydrocarbone

Biogenic Gas	Shale Oil	Condensate + Wet Gas	Shale Gas
Immature (0.2-0.45% Ro)	Mature (0.45- 0.9% Ro)?	Mature (0.9- 1.4% Ro)	Overmature (1,4- 3.0% Ro)

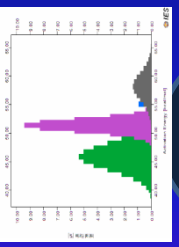
SR Potential

TOC : 1.0 -10%
Hydrogen Index > 250
(mg HC/G TOC)
PI- 0.01 to 0.03)

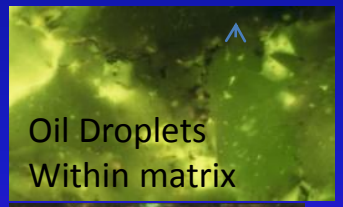
Condensate
API: >40°

TOC: <2.0%
Hydrogen Index
<100 mg HC/g TOC
PI> 0.15

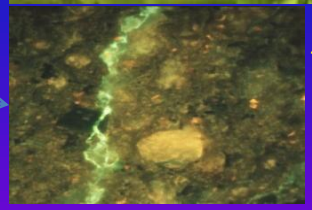
Kinetics



Organic Facies

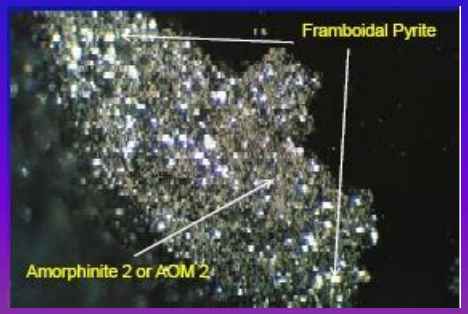


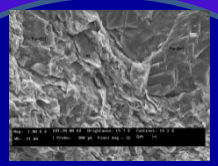
Original
Type I to II
kerogen



Oil Droplets
Or vein within
Source matrix

Original
Type II
kerogen





Mineralogy

Selected Maturation Issues in Conventional Resource Evaluation

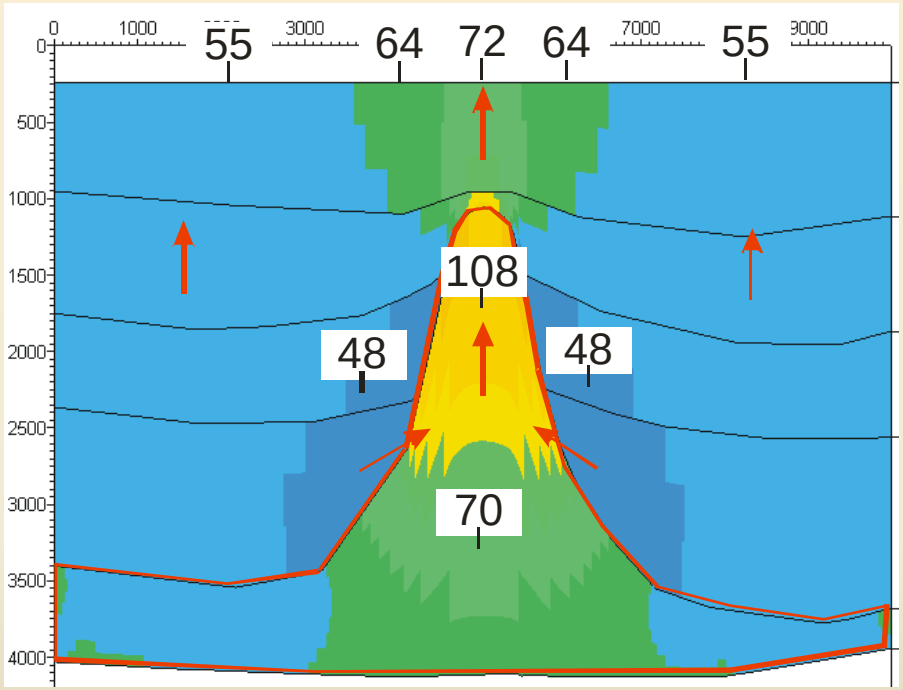
Deep to Ultra-Deepwater areas

- **Heat Flow, Reflectance Anomalies and**
- **Hydrocarbon Windows Calibration Associated with Salt**

Heat Flow Variability on the Diapiric Salt Body

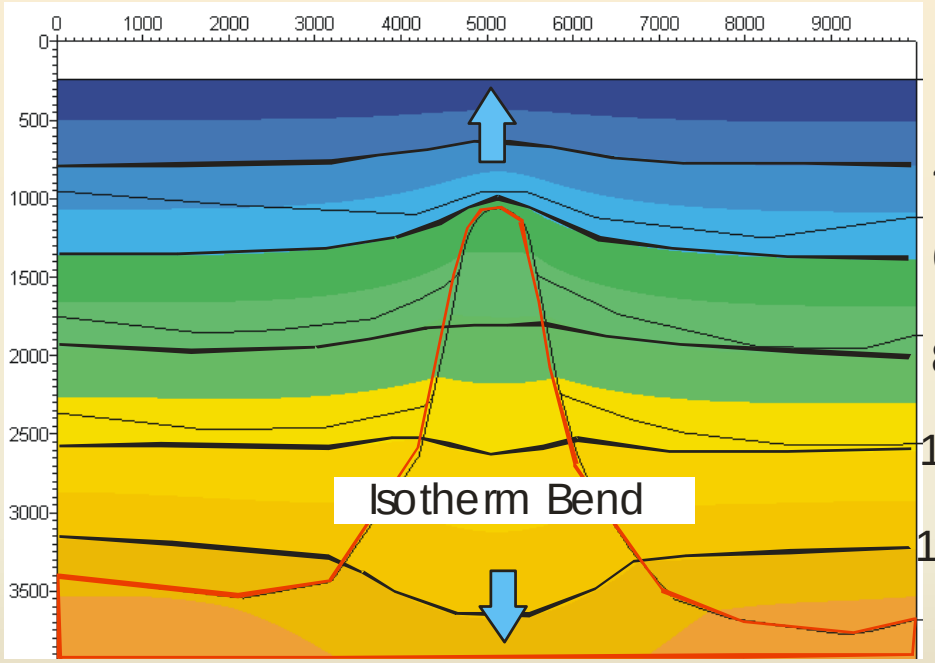
a)

Heat Flow in mW/m2



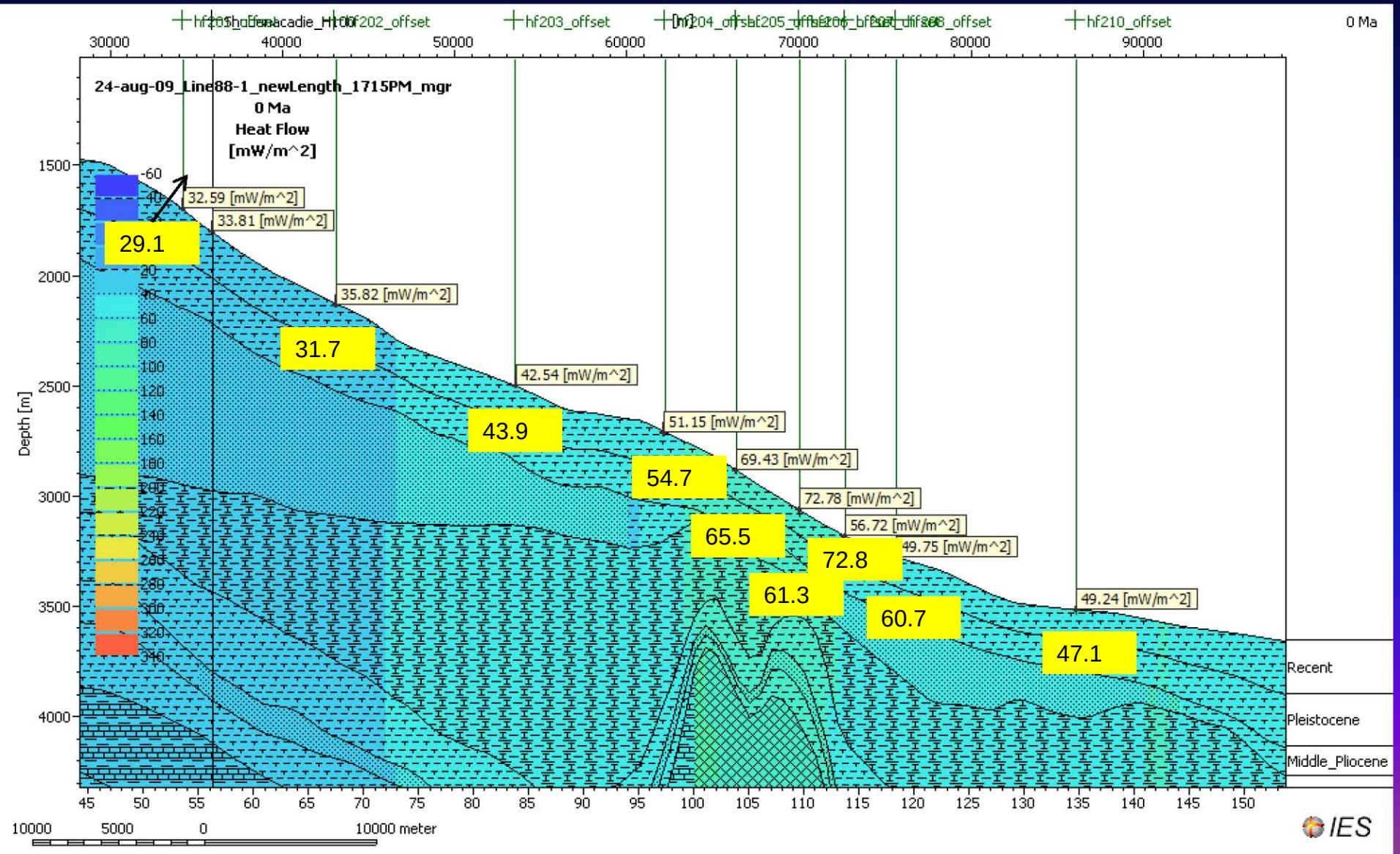
b)

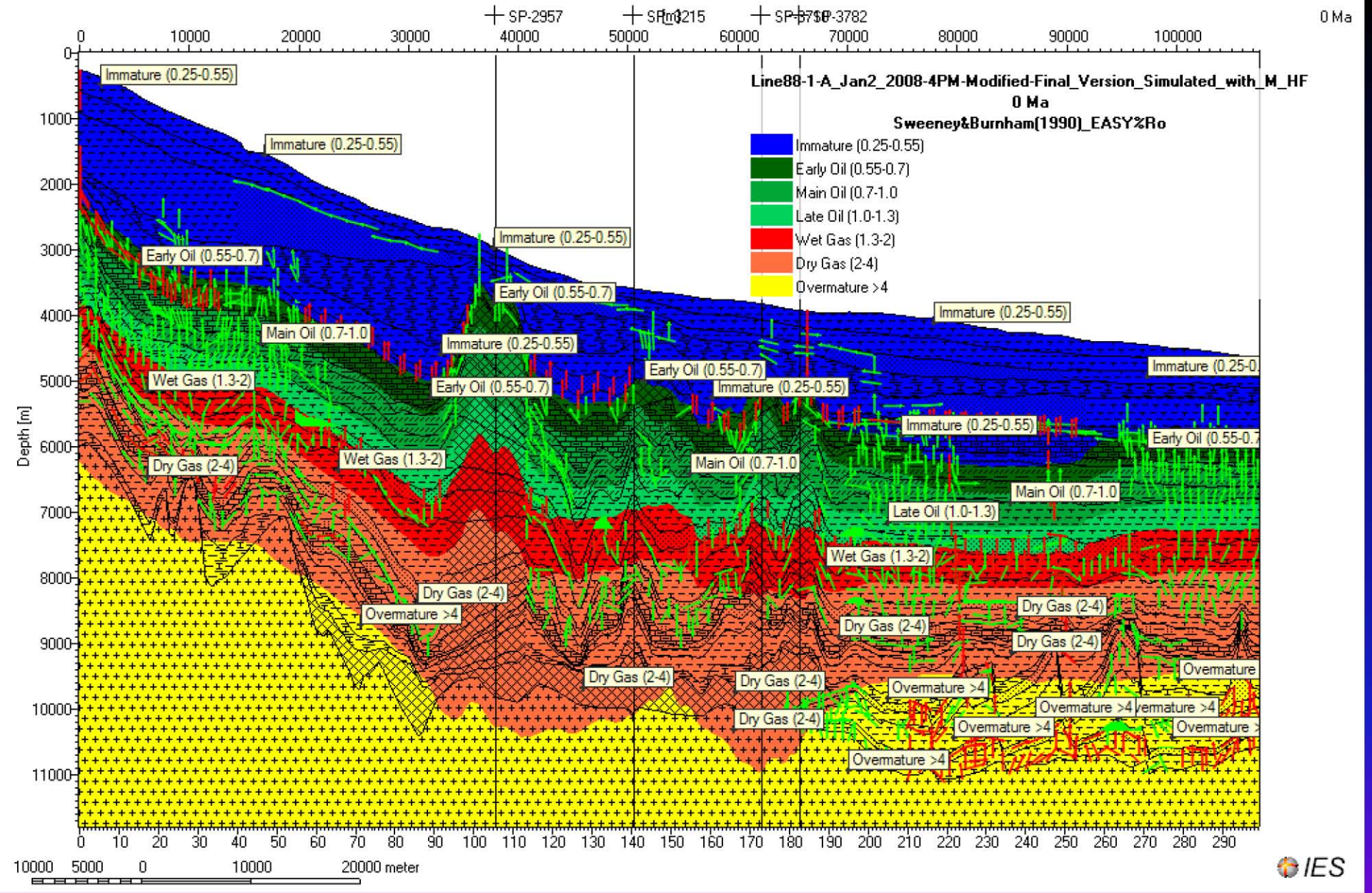
Temperature in Celsius



Courtesy: Thomas Hantschel; Schlumberger Inc. (Aachen, Germany)

Calibration of Measured and Modeled Heat Flow values

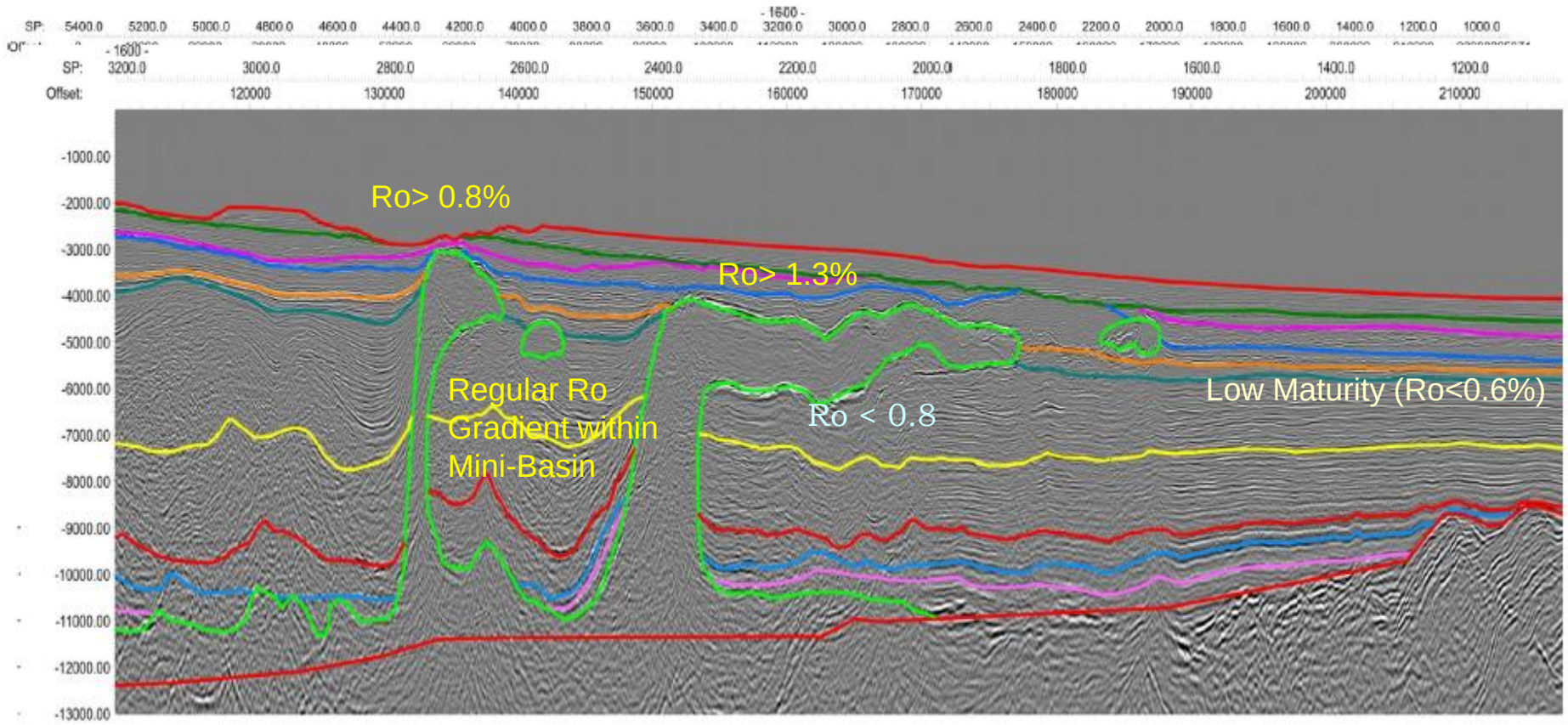




Modeled maturity values & window with migration vectors within and top of diapiric salt in Scotia Basin, Eastern Canada, based on measured vitrinite reflectance values from wells and selected measured data from seismic line 88-1A

Heat Flow and maturation variability associated with Salt Diapir and Salt Canopies

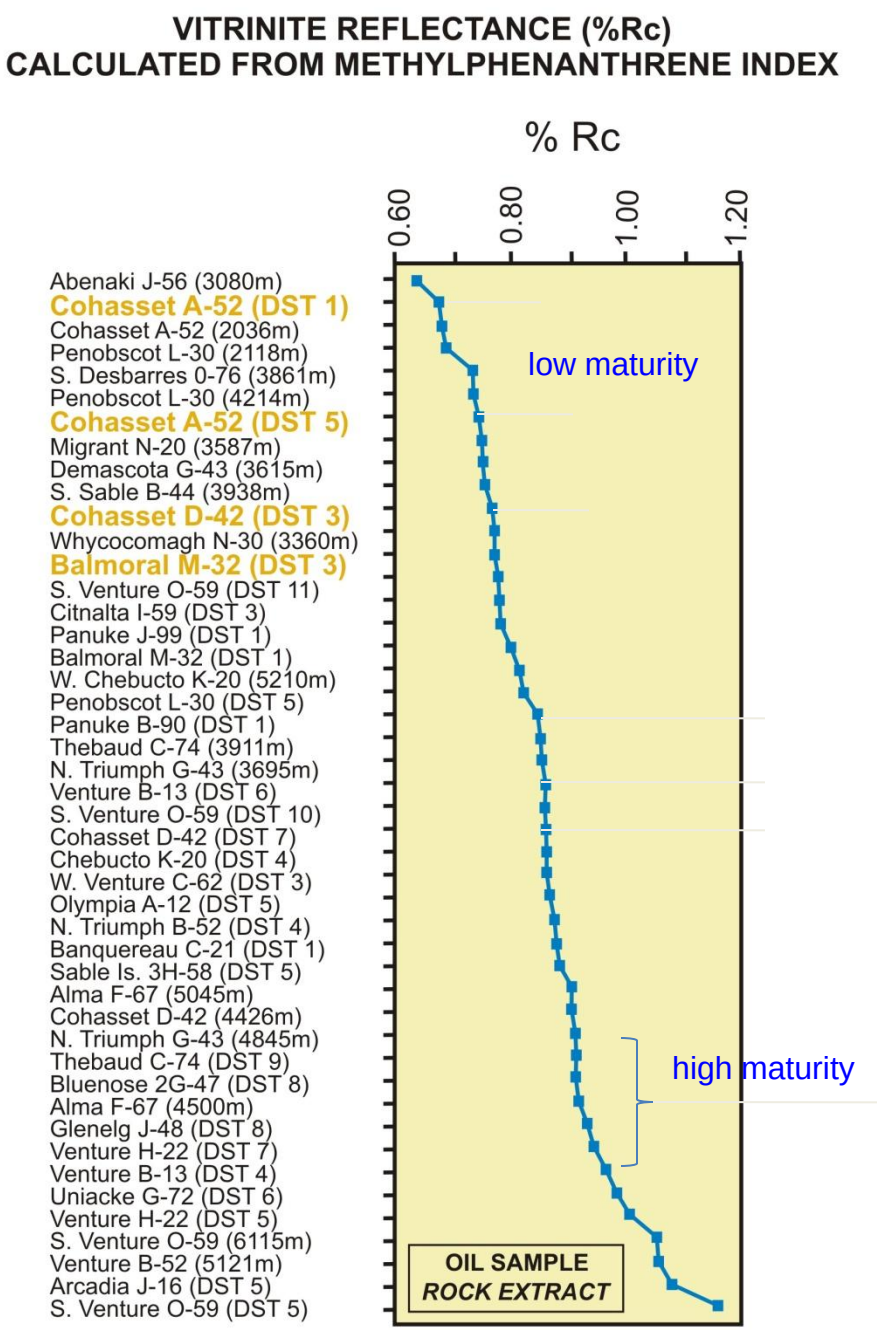
- Salt diapirs and canopies



Salt, Heat Flow, Maturation Effect on Oil or Gas Saturation

- **Source Rock associated with Subsalt Plays forms Oil in Deepwater plays because of the quenching of heat flow.**
- **Salt Withdrawal Zones will always have high Heat Flow and Oil and Gas would be related to their association.**
- **Source rock associated with salt diapir will have high Heat Flow and transform young immature source rock to oil.**
- **The source rock at the top of an Allochthinous Salt that is not rooted to the heated basement source will always have low or moderate heat flow with possible presence oil in the reservoir.**
- **The opposite to the Previous Statement, the source rock will behave similarly as on top of an diapir.**
- **The source rock in Ultra-Deepwater may be associated with an Oceanic Crust and may have a higher heat flow.**
- **The ultra-deepwater source rock or reservoir rock associated with salt may have volumetrically significant HC and often generate overpressure due to HC volume expansion.**

- **Correlation of Ro and Selected Chemical Maturity Parameter (Rc from MPI) in a condensate and gas-rich ultra-deepwater**
- **Scotian Basin**

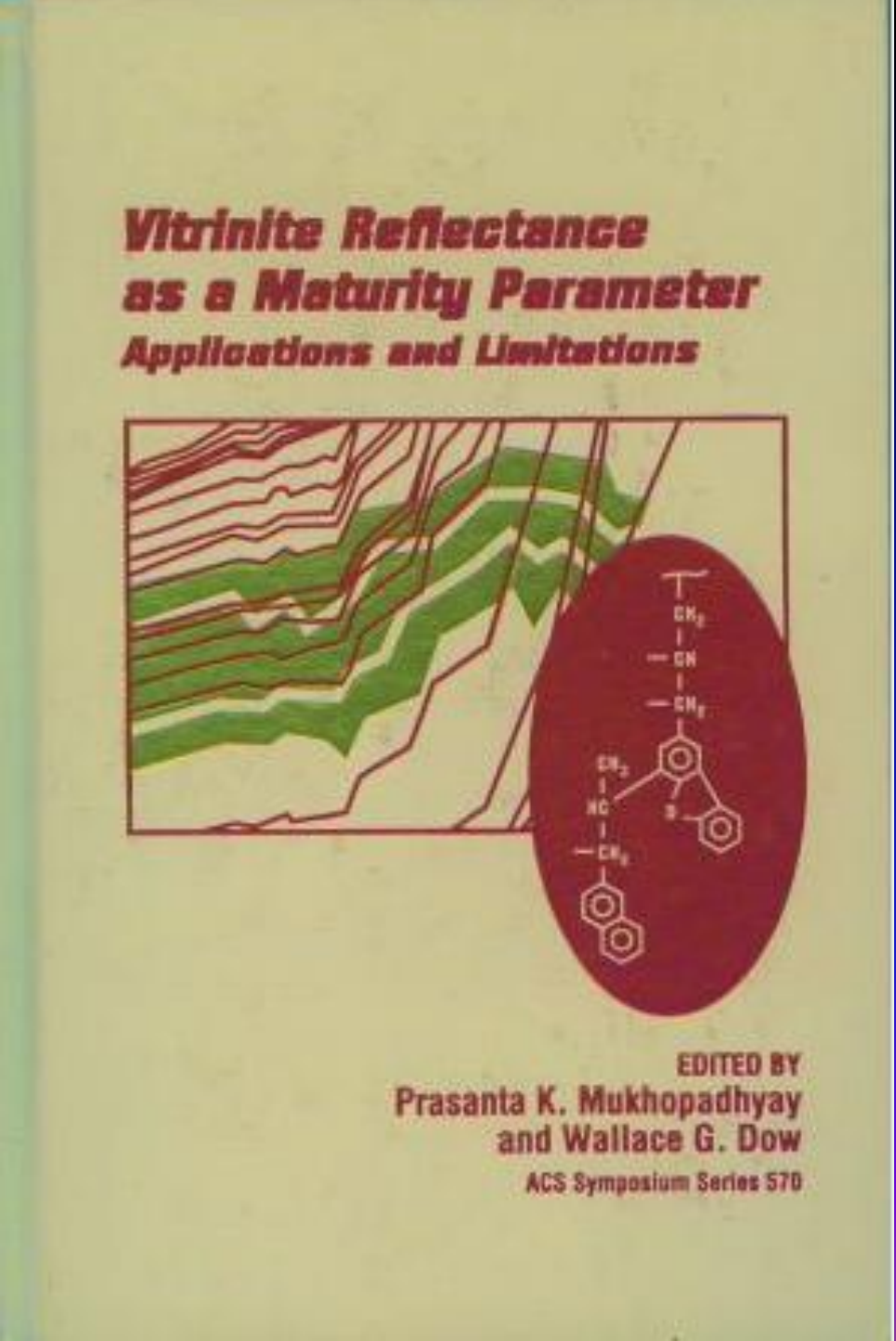


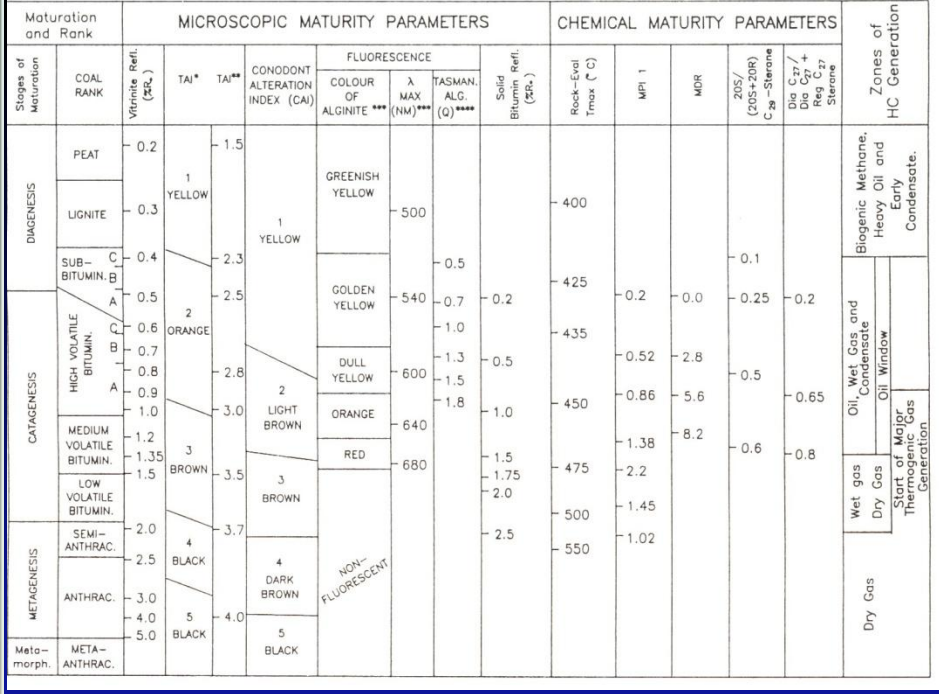
Courtesy: Mukhopadhyay et al. 1996; 2001

Rc: Calculated vitrinite reflectance Based on Methylphenanthrene Index 1 (MPI)

Comparison of Maturity of Light Oil, Condensate, Source Rock Extracts Comparing

VRo and MPI (Rc) Correlation





Thank You

Vitrinite Reflectance as a Maturity Parameter

Applications and Limitations

Edited by **Prasanta K. Mukhopadhyay** and **Wallace G. Dow**

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