How Plant and Animal Remains Become Oil and Gas: A Geochemical Perspective*

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Abstract

Oil source rocks (A.K.A. unconventional reservoirs) are formed by a series of processes which transform organic matter incorporated in sediments into oil and gas. Crude oil and most natural gas originate from hydrogen-rich organic matter, such as plankton, algae, anaerobic bacteria, pollen, and leaf cuticles. The process begins with high, primarily marine organic productivity and preservation in anoxic depositional environments. Very low temperature diagenesis liberates carbon dioxide from the organic matter which dissolves in interstitial water, forms organic acids, leaches carbonate minerals, and deposits "early diagenetic" calcite in fractures and pores. Diagenesis also transforms chemically unstable living organic matter into chemically stable kerogen.

Very early catagenesis (~0.5% Ro) converts part of the hydrogen-rich kerogen to solid bitumen which extrudes into and fills fractures and rock matrix pores. Continued heating and catagenesis successively forms crude oil, condensate/wet gas, and dry gas until ultimately only dry gas and graphite remain. Kerogen catagenesis is a volume-increase reaction which generates source rock internal pressure. When the pressure exceeds geostatic, the rock ruptures, oil and gases are expelled, the fractures close, and the source rock returns to near pre-generation porosity and pressure. This process is repeated many times as the source rock passes through the oil and gas generation maturity "windows" (~0.6 to 3.2% Ro+).

Oil source rocks generate about 60 bbls per acre foot for each 1% original TOC (Total Organic Carbon) they contain. A 75-ft- thick oil source rock with 5% measured TOC will generate about 29 million bbls of oil and gas equivalent per section by the time a maturity of ~3.0% Ro is reached. Because expulsion efficiencies are low, much of this oil and gas remain in the source rock, and in many cases the internal rock pressure as well (depending on the level of thermal maturity, overburden removal, and rock properties) is maintained, making mature oil source rocks attractive unconventional oil and gas reservoirs.

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HOW PLANT AND ANIMAL REMAINS BECOME OIL & GAS

A *GEOCHEMICAL* PERSPECTIVE

TGS Lunch Presentation
Tulsa, Oklahoma
September 27, 2011

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CIMAREX

REQUIREMENTS FOR SOURCE ROCK DEPOSITION

- *Production* of Organic Material
  Sunlight, Nutrients, Low Toxicity

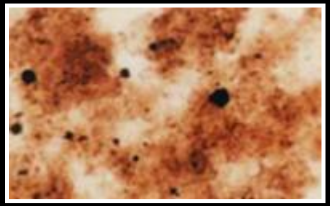
- *Accumulation* of Organic Material:
  Low Inorganic Sediment Contribution (Dilution)

- *Preservation* of Organic Material:
  Anoxic and/or Sub-Oxic Conditions (No Oxidative or Physical Destruction)

Demaison & Moore, 1980

BASIC ORGANIC MATTER TYPES

Amorphous (Marine & Lacustrine)



High Hydrogen

- Phytoplankton
- Bacteria
- Algae

Not *Stinking (Oxic)*

Terrigenous (Land Plants)

Low Hydrogen

- Angiosperms
- Gymnosperms
- Grasses

Devonian Life

STINKING SEA FLOORS

Anoxic – No Oxygen – No critters –

Hydrogen preserved – *Source Rocks Deposited*

No wonder there are so few geochemists!

Dead Zone

Bacterial Matt

REQUIREMENTS FOR SOURCE ROCK DEPOSITION

- Anoxic Environments:

  Stagnation – Layering of Waters of Different Salinities or Temperatures

  Oxygen Minimum Zones

  Ancient Marine Anoxic Events

- Model for Oxygen-Poor Marine Basins:

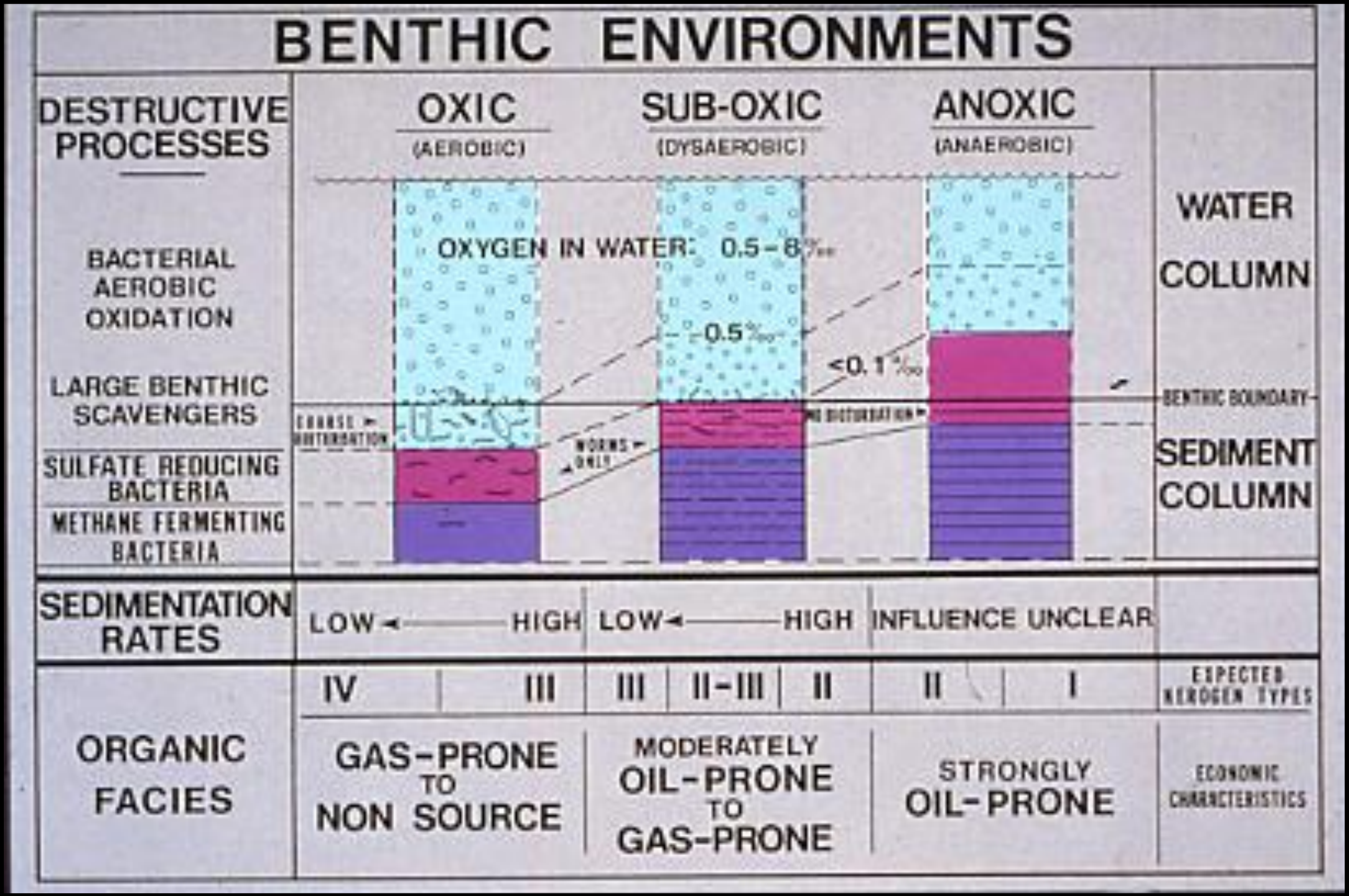
  Aerobic

  Dysaerobic (Sub-Oxic)

  Anaerobic (Anoxic)

Demaison & Moore, 1980

SOURCE ROCK DEPOSITION

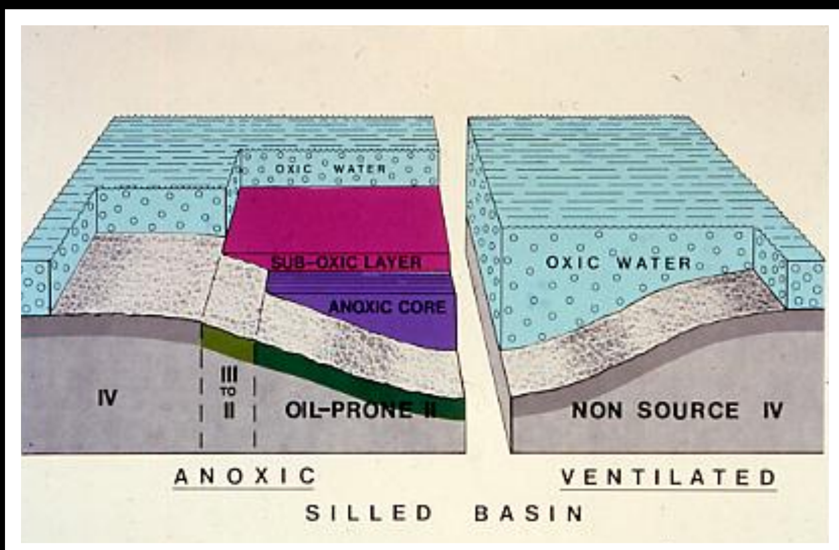


Demaison & Moore, 1980

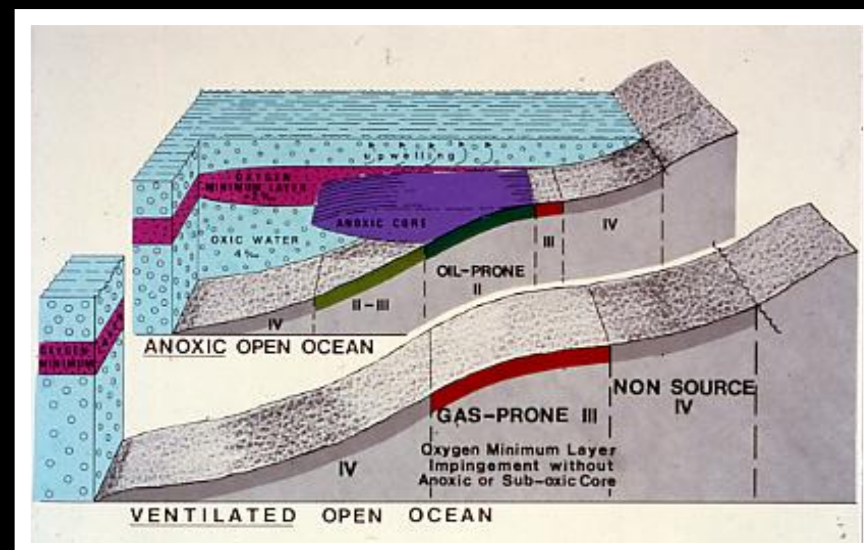
SOURCE ROCK DEPOSITION

Hydrogen Preserved Best in Purple, Anoxic Zones

Silled Basins



Oxygen Minimum Zones

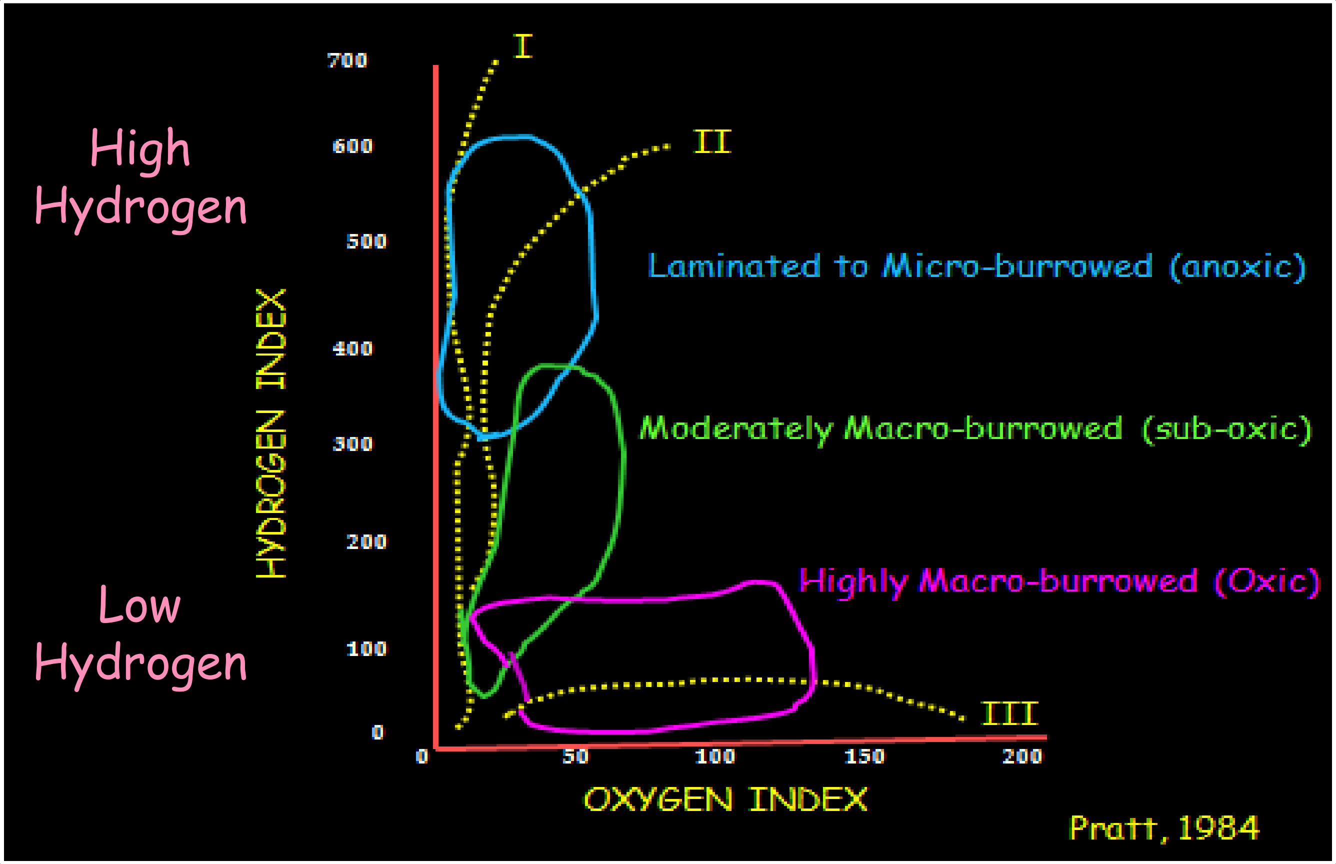


Demaison & Moore, 1980

STINKING SEA FLOORS

Anoxic – No Oxygen – No critters – *Hydrogen preserved*

CRETACEOUS SHALES, CO. *All high % amorphous, low %Ro*



HOW OIL & GAS ARE MADE FROM PLANT/ANIMAL REMAINS

Living Organic Material – Unstable after death

Diagenesis

Little or no Heat

Kerogen - Chemically Stable

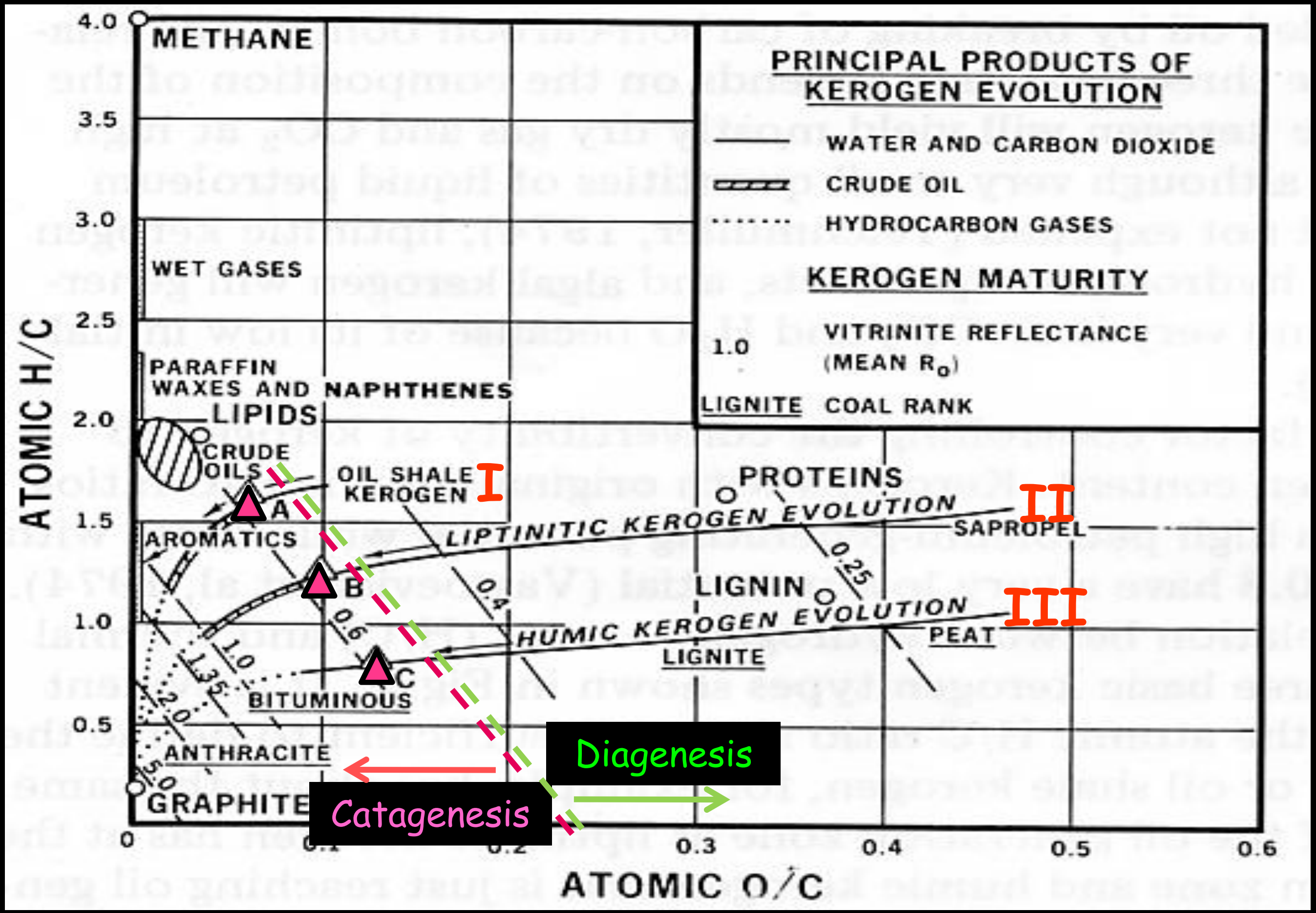
Catagenesis

Low to High Heat

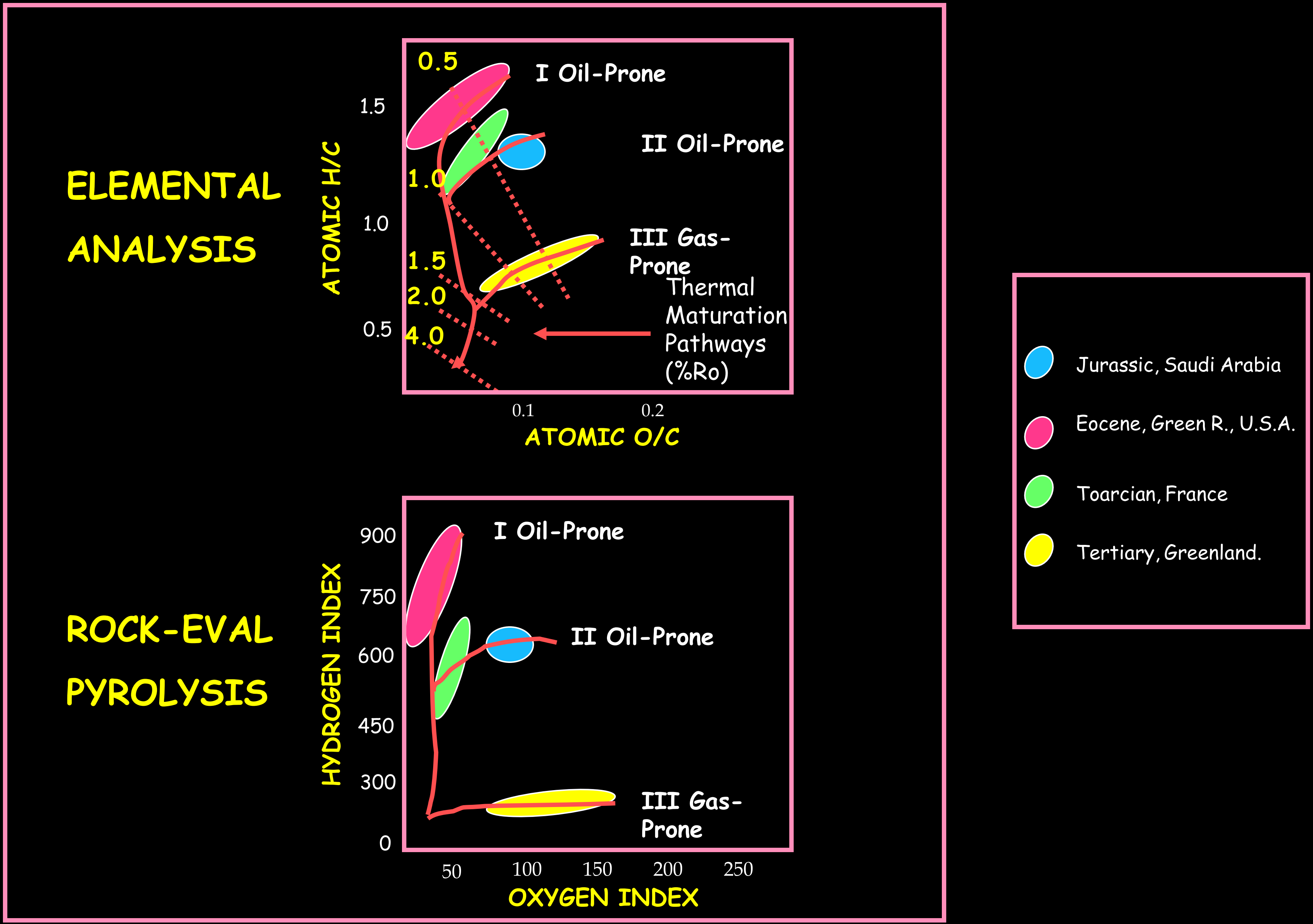
Oil & Gas - Thermally Stable




KEROGEN DIAGENESIS & CATAGENESIS PATHWAYS



Dow, 1977



ELEMENTAL
ANALYSIS
ROCK-EVAL
PYROLYSIS
ATOMIC H/C
1.5
1.0
0.5
0.5
1.0
1.5
2.0
4.0
I Oil-Prone
II Oil-Prone
III Gas-Prone
Thermal Maturation Pathways (%Ro)
0.1
0.2
ATOMIC O/C
HYDROGEN INDEX
900
750
600
450
300
0
I Oil-Prone
II Oil-Prone
III Gas-Prone
50
100
150
200
250
OXYGEN INDEX
Jurassic, Saudi Arabia
Eocene, Green R., U.S.A.
Toarcian, France
Tertiary, Greenland.

Peters, 1986

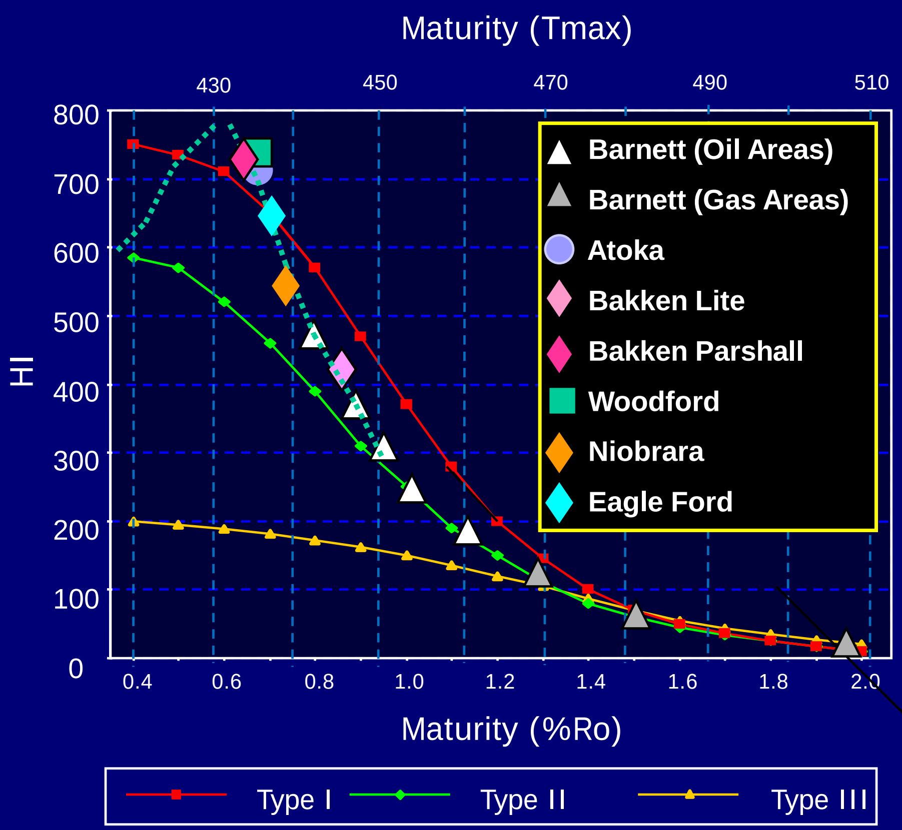
KEROGEN MATURATION TRENDS

The rate and magnitude of HI reduction (ΔHI) during pyrolysis and natural maturation is a function of the original kerogen type.

Data shows a consistent trend of increasing HI loss with increasing maturity of the original, immature kerogen in the zone of catagenesis (0.5 to 2.0 % Ro).

Rock-Eval Tmax is calibrated to %Ro with the following equation: % Ro = 0.018 x Tmax - 7.16 (Jarvie, et al, 2001).

Most oil source rocks are type II kerogen, type III will generate only gas, and type I is rare (Green River, Monterey, etc.). Plot shows mid-points of HI range.



W. DOW, 1985

HOW ARE OIL & GAS MADE FROM PLANT/ANIMAL REMAINS?

Living Organic Material – Unstable after death

Diagenesis

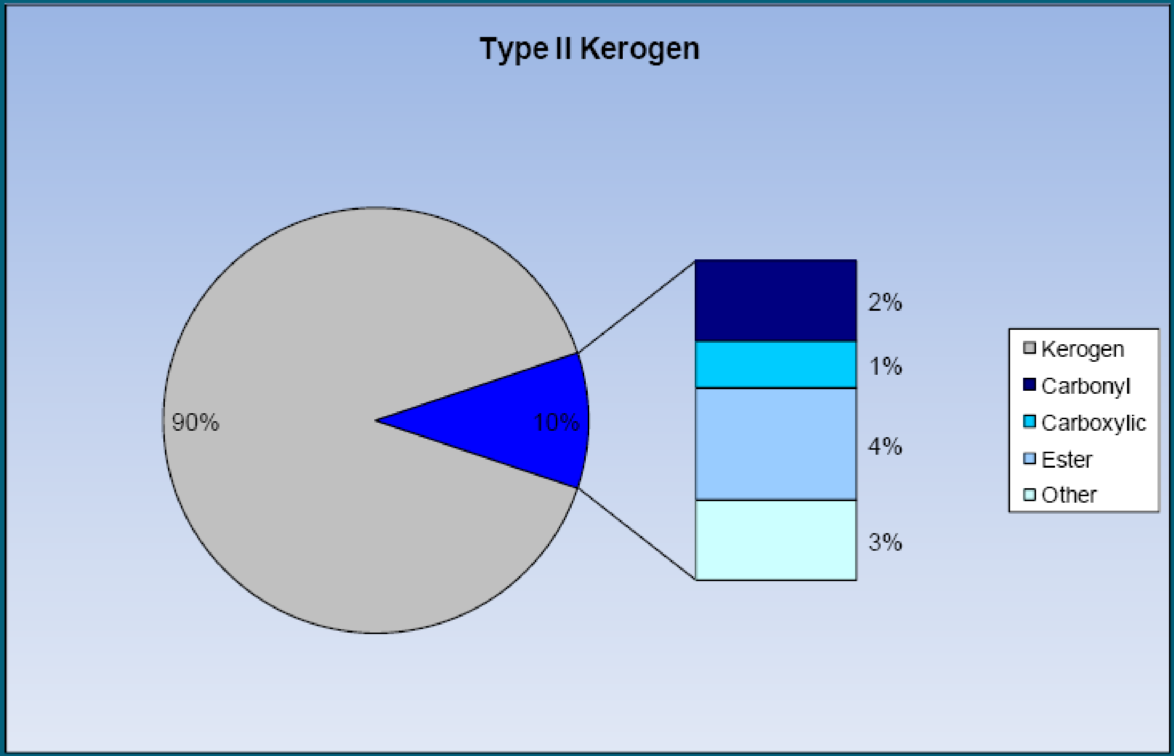
Organic Acids

Kerogen - Chemically Stable

Catagenesis

Thermally Stable - Oil & Gas

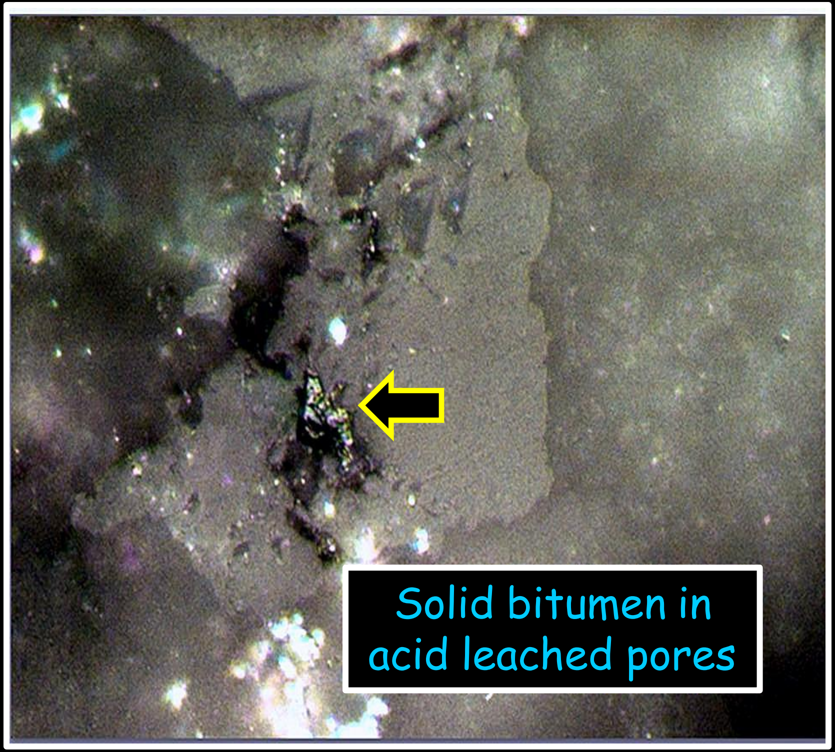
Oxygenated Compounds Evolved from a Low Maturity Type II Kerogen

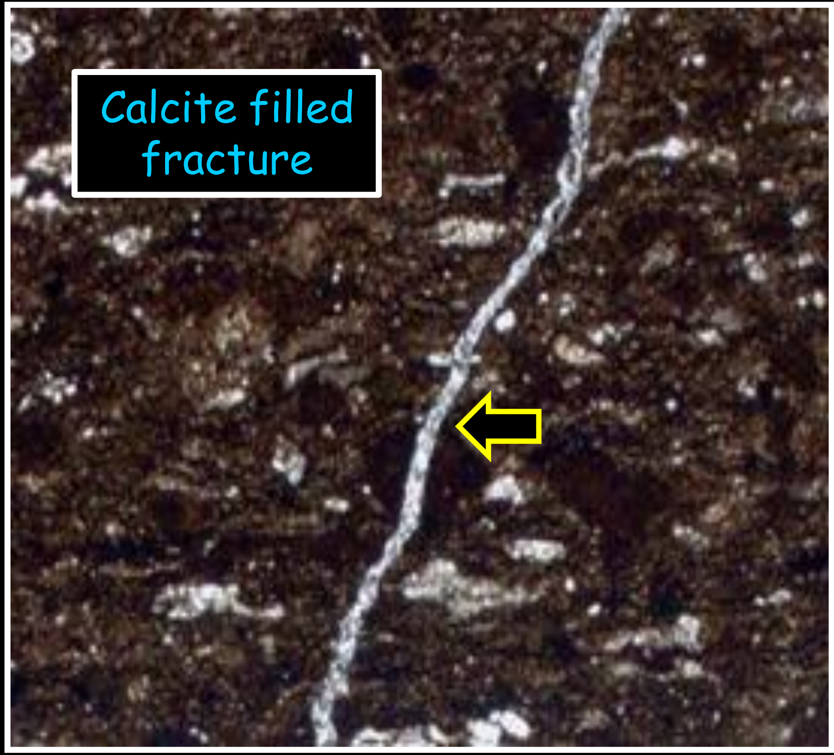


DIAGENESIS REACTIONS

KEROGEN ➡ $CO_2 + H_2O$ = CARBONIC ACID

LEACHES CARBONATES & PRECIPITATES CALCITE





HOW ARE OIL & GAS MADE FROM PLANT/ANIMAL REMAINS?

Living Organic Material – Unstable after death

Diagenesis

Solid Bitumen → Kerogen - Chemically Stable

Catagenesis

Oil & Gas – Thermally Stable

GILSONITE IS SOLID BITUMEN

Uinta Basin GILSONITE is a *solid bitumen composed mainly of resins and asphaltenes* with minor amounts of saturated and aromatic hydrocarbons. *Gilsonite and solid bitumen are low maturity products (<0.5% Ro).*

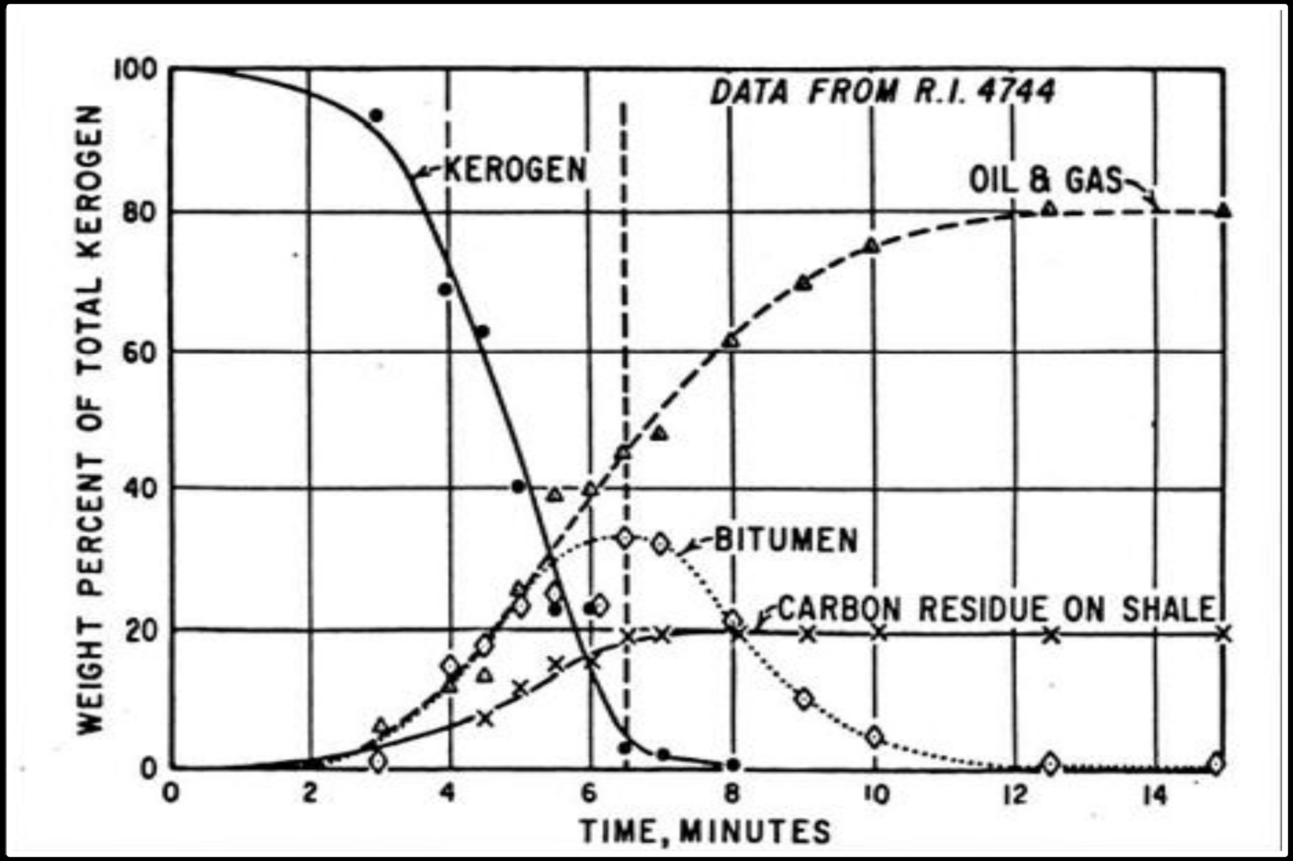
*Gilsonite dikes originated as hydraulic extension fractures, caused by local overpressure in the *very organic rich Eocene Green River oil shales, were filled with extruding gilsonite in a plastic state.*

GILSONITE

**very organic rich layers are essential for solid bitumen emplacement.*

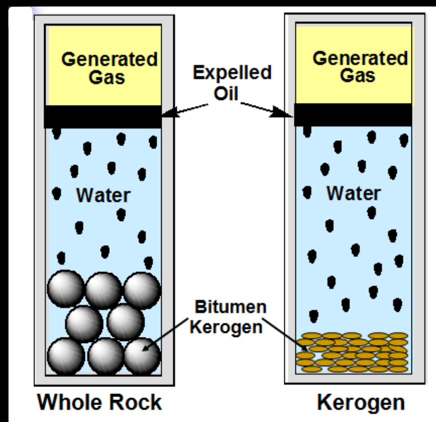
Peters et al., 2004

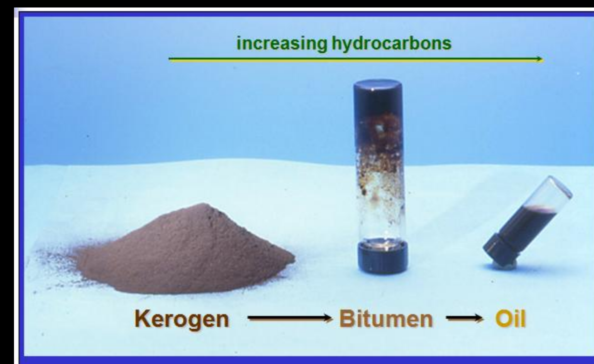
OIL SHALE RETORT PRODUCTS IN THE LABORATORY

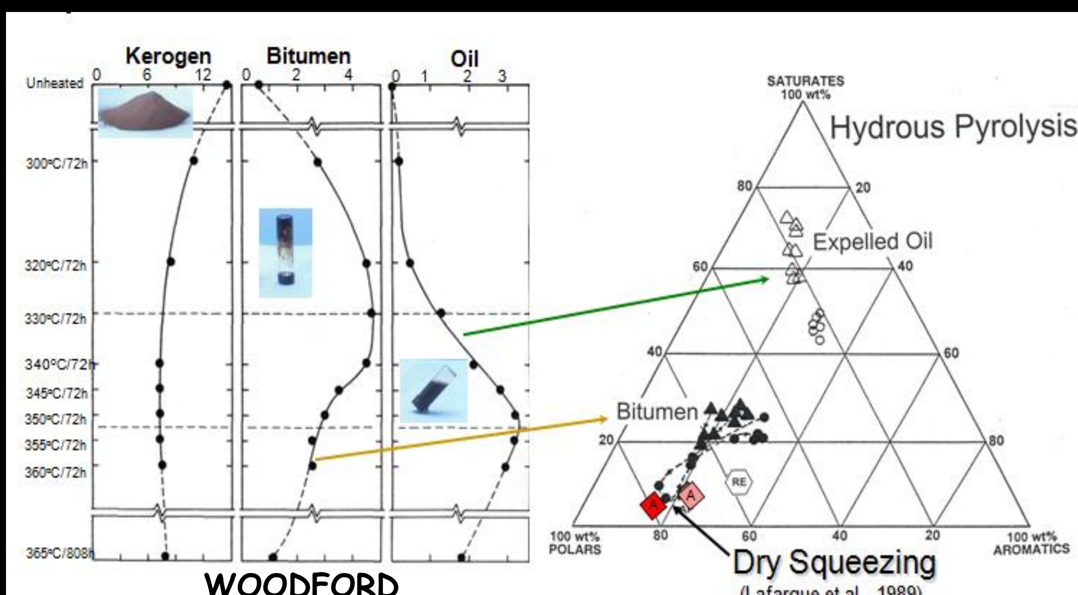


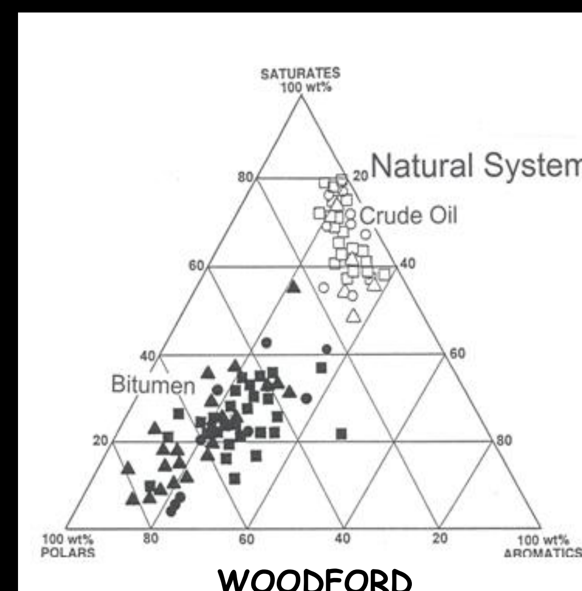
Allred, 1967

HYDROUS PYROLYSIS PRODUCTS IN THE LABORATORY



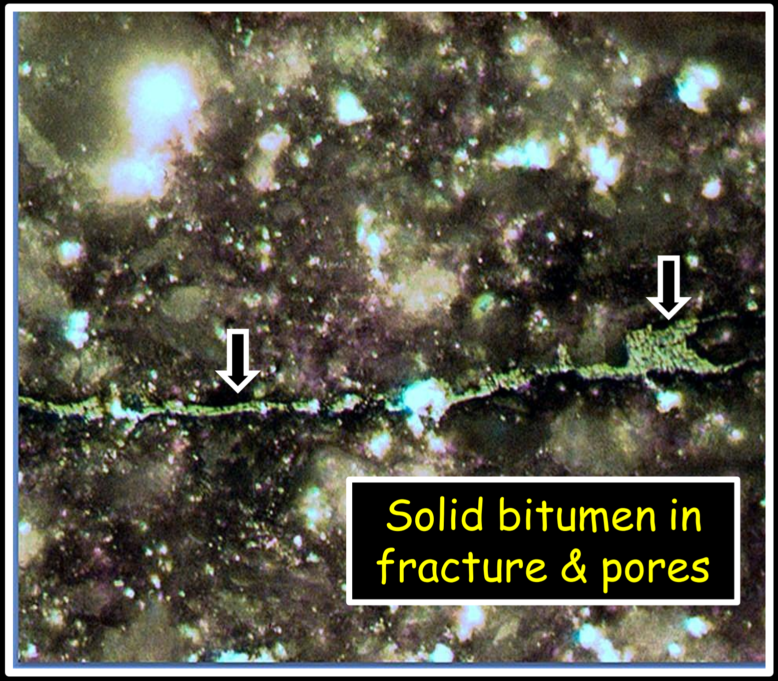




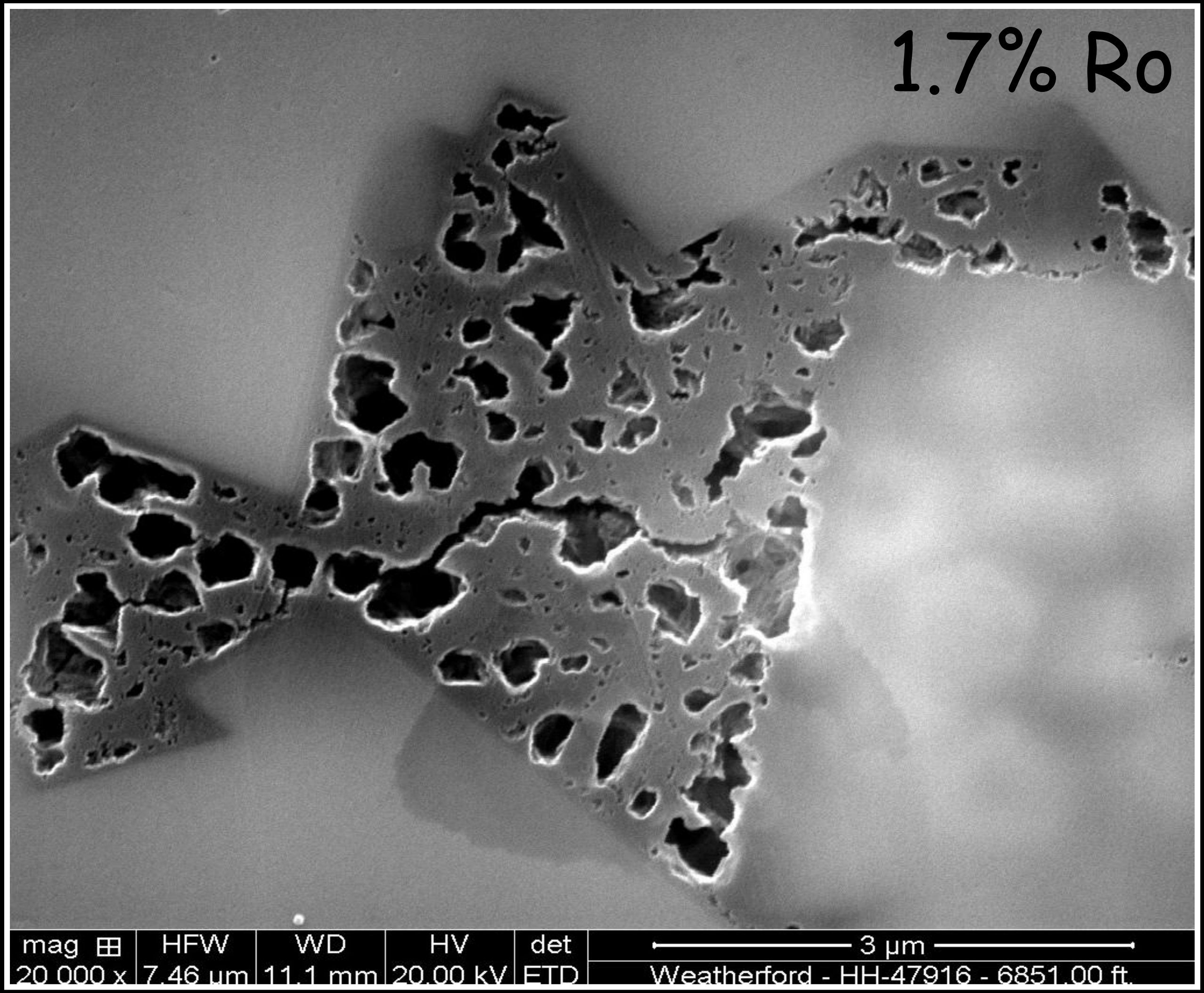


Lewan, 1997

SOLID BITUMEN IN REFLECTED LIGHT MICROSCOPY



Porosity in Solid Bitumen



HOW ARE OIL & GAS MADE FROM PLANT/ANIMAL REMAINS?

Living Organic Material – Unstable after death

Diagenesis

Kerogen - Chemically Stable

Crude Oil

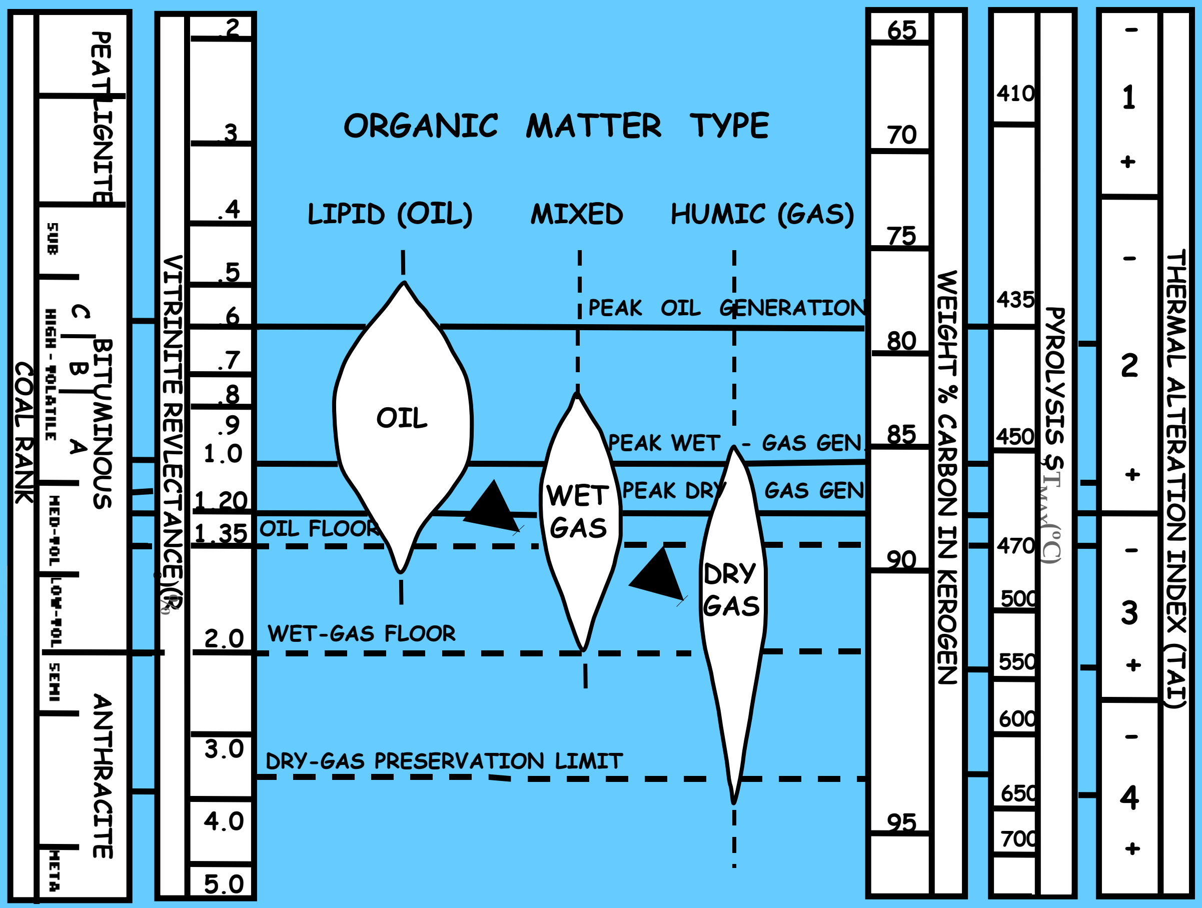
Condensate

Dry Gas

Catagenesis

Oil & Gas – Thermally Stable

ZONES OF PETROLEUM GENERATION AND DESTRUCTION



CORRELATION OF VARIOUS MATURATION INDICES AND ZONES OF PETROLEUM GENERATION AND DESTRUCTION

DOW 1977

CONCEPTUAL MODEL OF OIL AND GAS GENERATION

- Organic-rich source rocks are exposed to heat during burial.
- A portion of the kerogen is converted solid bitumen and then to oil and gas.
- This results in a ~4% volume increase which increases the porosity and internal pressure of the source rock.

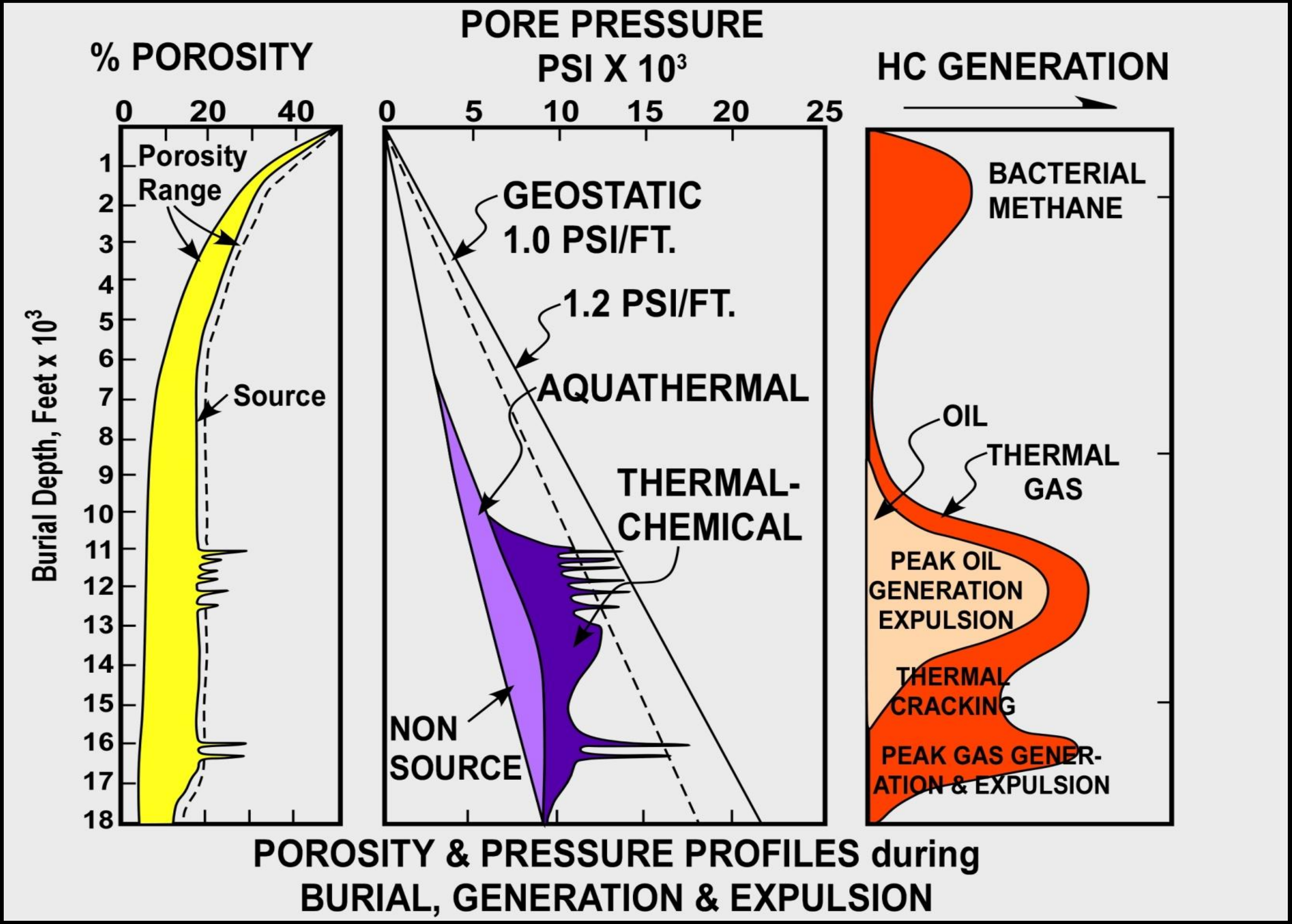
Momper, 1979

CONCEPTUAL MODEL OF OIL AND GAS GENERATION

- When the pressure exceeds geostatic, the rock ruptures, oil and gas are expelled, the fractures close, and the source rock returns to near pre-generation porosity and pressure.
- This process is repeated many times as the source rock passes through the oil and gas generation maturity "windows".
- Oil expulsion is *very inefficient* and ~80% of the oil generated never leaves the source rock (unconventional reservoirs) and ultimately is converted to condensate and then to wet gas and ultimately dry gas and graphite.

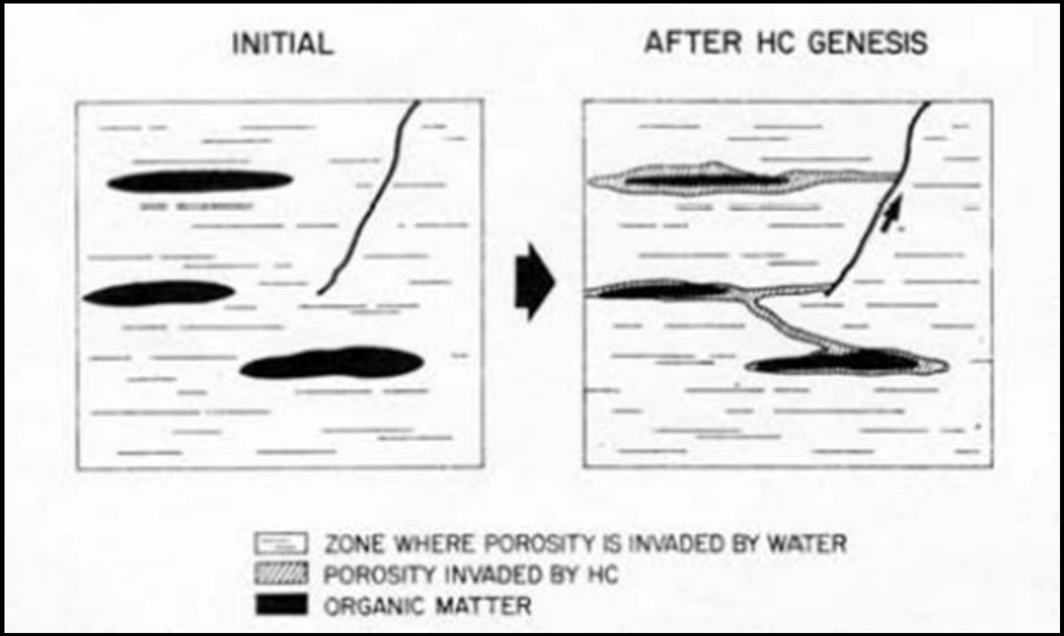
Momper, 1979

POROSITY, PRESSURE & OIL & GAS GENERATION



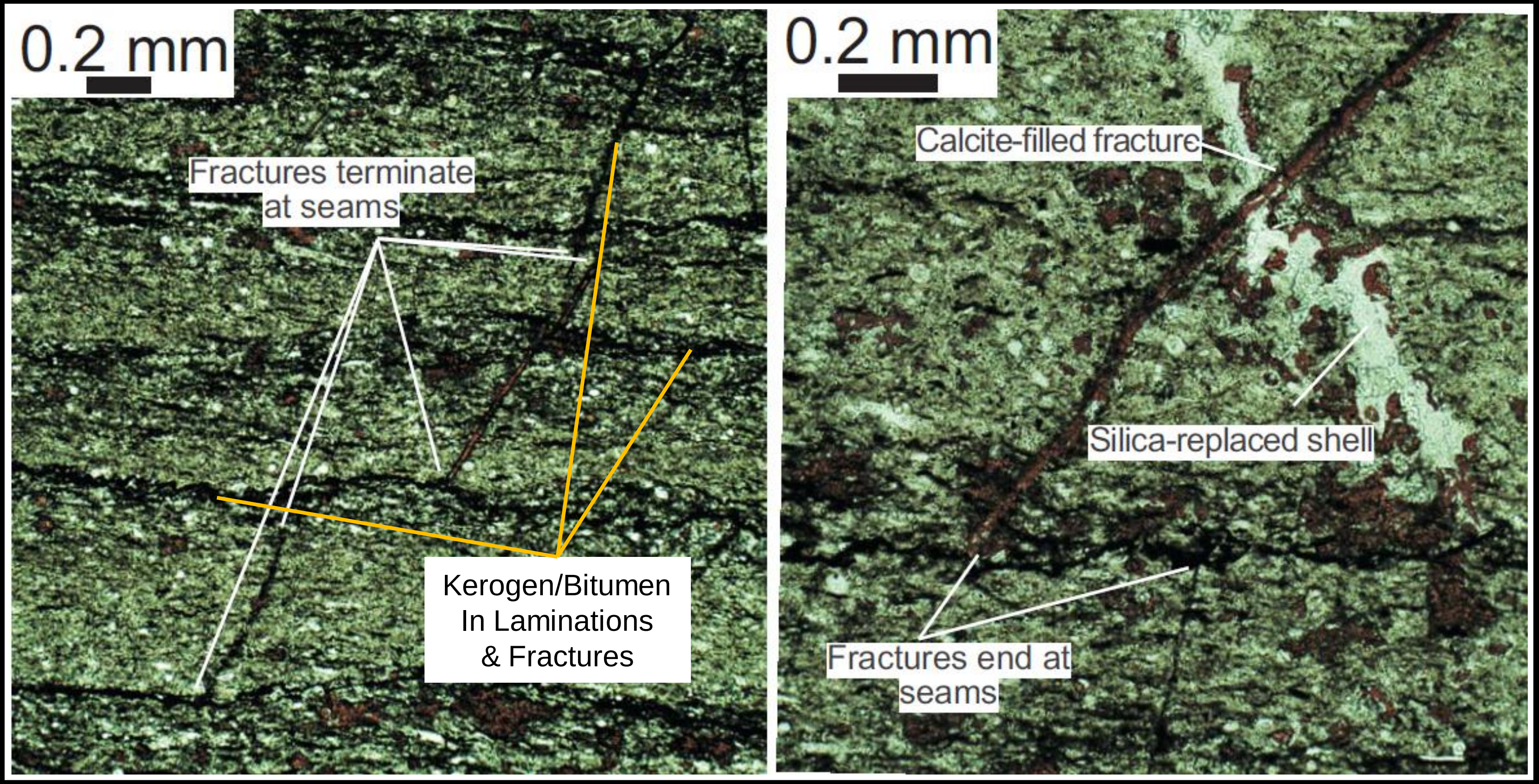
Momper, 1979

PRIMARY MIGRATION OCCURS ALONG BEDDING AND FRACTURES



Ungerer, et al, 1981

PRIMARY MIGRATION OCCURS ALONG BEDDING AND FRACTURES



Loucks, 2009

HOW MUCH OIL DO SOURCE ROCKS GENERATE?

- Oil source rocks *generate* about 60 bbls per acre foot per *original* 1% TOC by 1.4% Ro.
- A *75 –foot-thick* oil source rock with a *5% measured TOC* (10% *original*) has *generated about 29 million bbls of oil per section.*
- At 20% expulsion efficiency, 6 million bbls are expelled and 23 million bbls remain in the source rock.
- At 4% recovery for unconventional reservoirs = 922,000 bbls of *producible oil* per section .

Schmoker, 1994

"UNCONVENTIONAL" RESERVOIRS

Calvin and Hobbs by Bill Watterson

My source rock is now my reservoir!

Quinn R. Passey, 2010

But that's another story.