Definition, Modes of Occurrence and Pitfalls in Understanding the Term 'Bitumen' in Conventional and Unconventional Petroleum Systems*

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Abstract

Definition

With a viscosity >10,000 cP at reservoir temperature, bitumen is effectively 'solid petroleum' on a production timescale. Because its density, including any dissolved gas, may reach or exceed that of water, it has little or no buoyancy. Heavy oil has lower viscosity, is less dense than water and is buoyant. The term 'tar' is used synonymously with both: Athabasca 'Tar Sands' in Canada are mined for their bitumen; the Orinoco 'Tar Belt' wells in Venezuela produce heavy oil.

Modes of Occurrence

One form of bitumen originates as a petroleum liquid phase that accumulates under its own buoyancy and is subsequently altered in the accumulation, either through biodegradation or de-asphalting by addition of light saturate compounds to a liquid phase. The second form is transitional with OM/kerogen: it is organic matter (OM) whose structure has been mechanically weakened by bond breakage during maturation. Lacking the ability to migrate under its own buoyancy, it can only be re-distributed under the overburden load within the source bed - and sometimes well beyond in bitumen dykes. This is a non-Newtonian fluid whose characteristics change from solid to mobile in response to high pressure and temperature. Looking at a microscopic or macroscopic (outcrop) section, any OM that is seen in a load-bearing position is a non-Newtonian fluid. Further,

there is no alteration mechanism to turn an original petroleum fluid into bitumen in the tiny pores of fine-grained rocks. Bitumen extrusion is not petroleum phase migration! Inside the source bed, this bituminized OM is squeezed into load-protected positions where open pores can develop within it – this state of mechanical evolution usually coincides with the late oil expulsion window and the gas expulsion window – hence the OM-hosted porosity of gas 'shales'. During this redistribution, the mechanically weakest parts of the OM will be among the remaining reactive kerogen moieties, rather than in the aromatizing inert kerogen, leading to a preferential mobilization and 'mechanical sifting' that favors the development of porosity in the extruded bitumen – as commonly observed in SEM images.

Pitfalls

By definition, bituminized kerogen is measured in the Py2 (S2) yield and thus its decomposition is measured and modeled as part of kerogen decomposition. There is no need to model an intermediate 'bitumen phase'. Geochemists cause unnecessary confusion when they use the term as a synonym for Extractable Organic Matter or EOM.

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http://www.thisispetroleumsystems.com/products/tps-petroleum-systems-studies/

Definition, modes of occurrence and pitfalls in understanding the term 'bitumen' in conventional and unconventional petroleum systems

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Importance of understanding 'bitumen'

Understanding of bitumen impacts a wide range of Petroleum E&P topics - including but not limited to the following topics in this presentation:

- Origin of floating asphalt blocks documented since biblical times in the Dead Sea
- Significance for Deep Water Gulf of Mexico exploration of solid and liquid petroleum shows in DSDP cores in the Straits of Florida
- Origin of $100mm drilling problems in the deep water Gulf of Mexico
- Mechanism of porosity occlusion in potential unconventional 'shale oil' reservoirs
- Hosting of porosity creation in potential unconventional 'shale gas' reservoirs

Outline

The problem

- The term bitumen continues to be used to describe numerous petroleum system elements with different chemical and physical origins

Mechanisms

- Evolution of OM to bitumen is a physical state change, not the creation of a discrete chemical intermediate between kerogen and petroleum
- Both OM and bitumen are converted into a migrate-able petroleum fluid phase and themselves into a porous reservoir medium

Extractable Organic Matter (EOM)

- OM, bituminized OM and petroleum fluids can be extracted with organic solvents
- SARA of bitumen extracts resemble OM not liquid petroleums

Summary cartoon of bituminization in source rocks

Bitumen as considered in today's talk

Robust physical definition exists. Bitumen…

- …has a viscosity of > 10,000 cP at reservoir temperature. Conversely, heavy oil and all other petroleum fluids have viscosity <10,000 cP
- …is a Non-Newtonian fluid. Need to squeeze it to make it move - e.g. ketchup, toothpaste, halite in salt basins

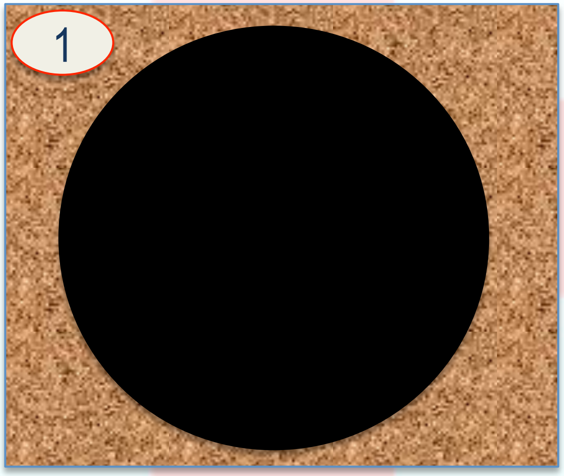
Many geochemical paths lead to bitumen

- This talk will not consider bitumen that results from **biodegradation** of an originally mobile fluid phase, e.g. Canadian "oil sands" bitumen
- …nor bitumen that **precipitates in a phase change** during petroleum accumulation or production in reservoirs, e.g. "tar mats"
- …nor bitumen that **precipitates during oil-gas cracking** as a carbonaceous residue (required due to hydrogen balance) in a very hot reservoir, e.g. deep Smackover-Norphlet system, GoM

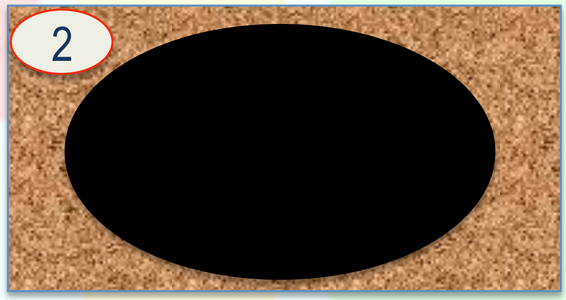
It is about bitumen originating in and emanating from source beds

Evolution OM-Bitumen-Petroleum

Shallow Burial: OM fragment

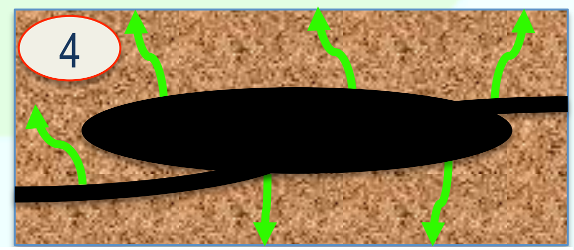


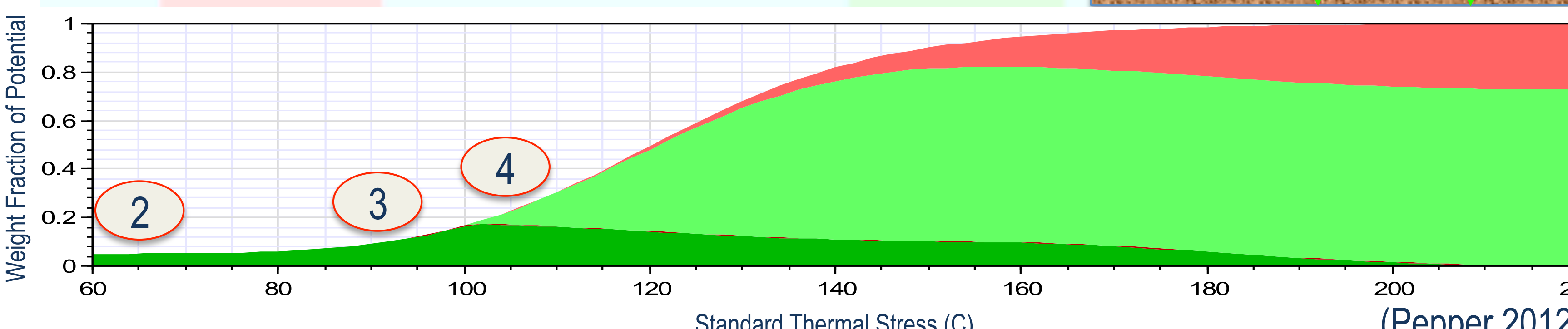
STS < 80 °C; PI <0.05: OM is mechanically compacted and water is expelled from it



STS ~ 80-100 °C (A; higher for other organofacies); PI ~ 0.05-0.2: becomes mechanically weak – loading extrudes "bituminized" OM. Occurs preferentially in OM with early generation kinetics and high HI

STS > 100 °C (A; higher for other organofacies): Following saturation of sorptive sites in *in-situ* and extruded "bituminized" OM, expelled molecules collect outside the OM to form a discrete fluid phase which begins the process of primary migration

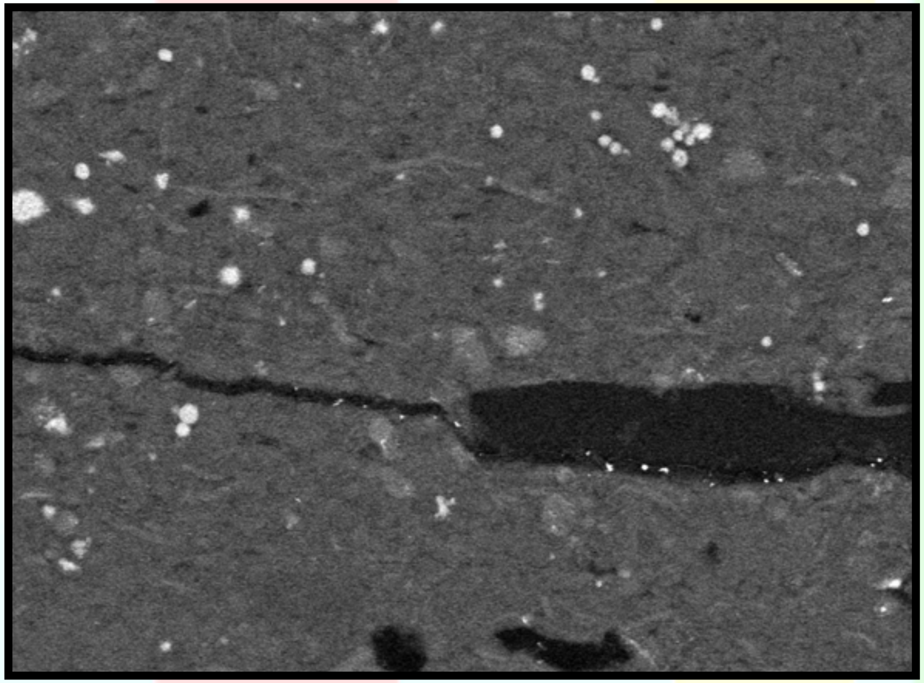




(Pepper 2012)

Bituminized OM extrusion occurs at all scales

Microscopic - SEM



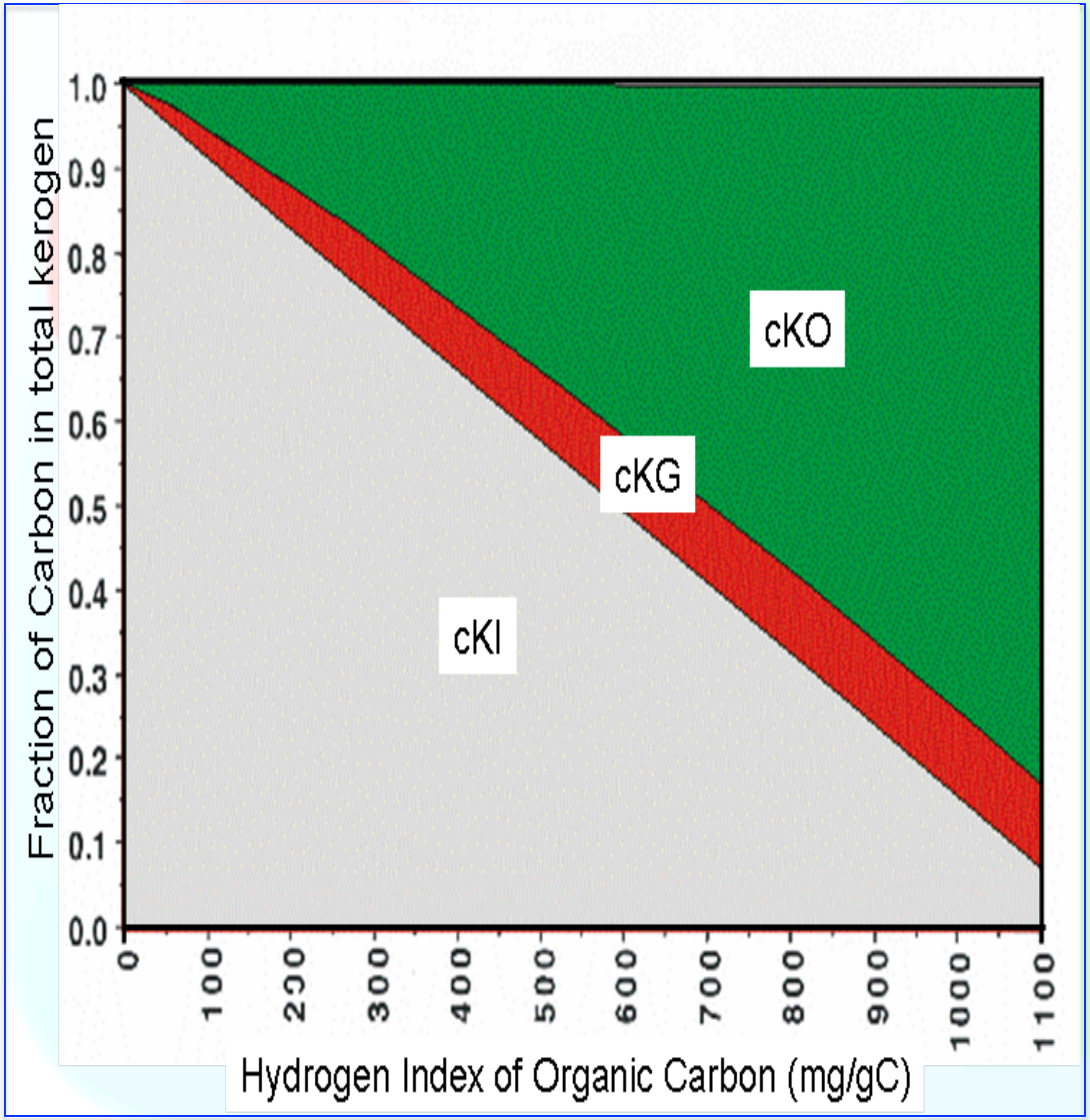
Bitumen sill emanating from Tasmanite algal body in Bakken Formation source rock (Wally Dow, pers. comm.)

Note size of OM particle >> mineral matrix particles – OM and bitumen sill are under overburden stress

Macroscopic - outcrop

Neuquen Basin, bitumen dyke extruded from Vaca Muerta Fm (Parnell and Carey 1995)

Linkage between HI and bitumen extrusion



Hydrogen Index

- Reflects the ratio of reactive, oil and gas generating carbon (cKO and cKG) vs. inert carbon (cKI)

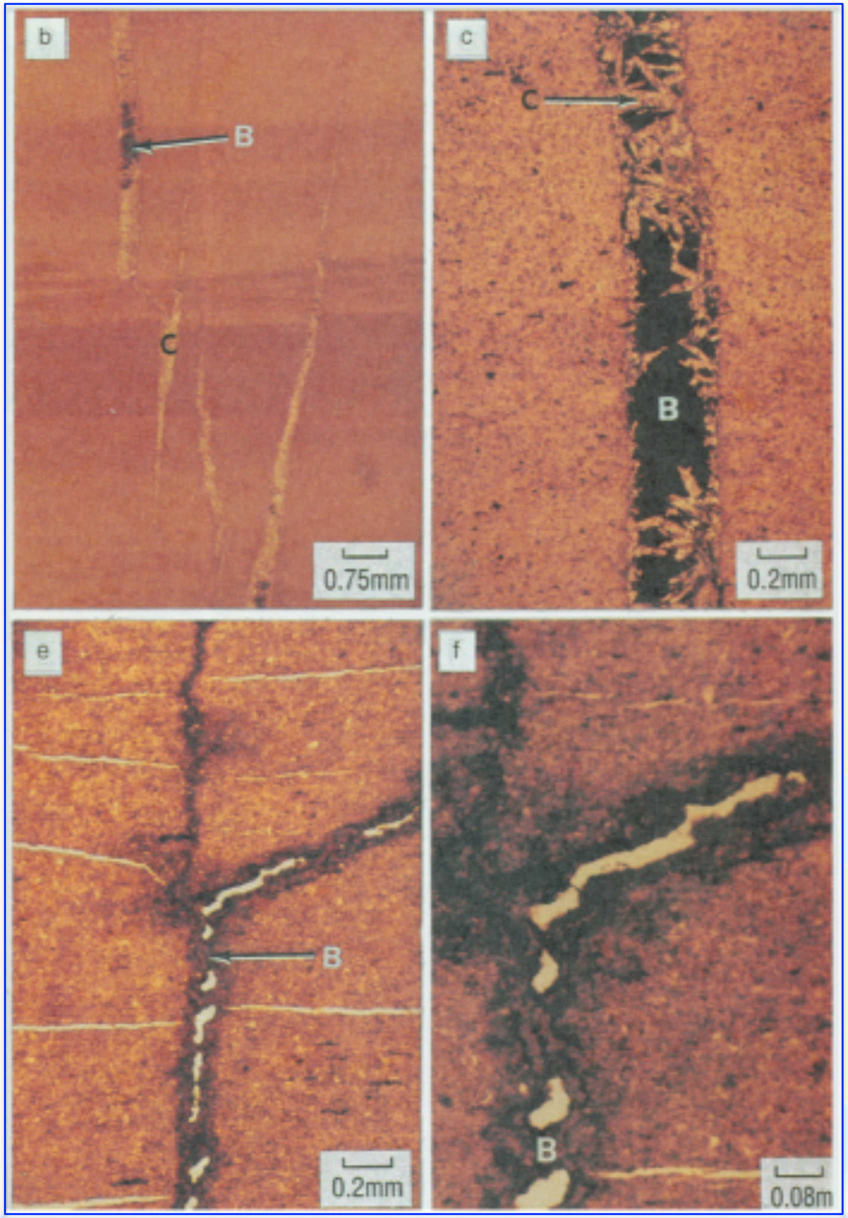
OM with high HI

- Small amount of transformation results in a weakening of a large proportion of the structure

OM with low HI

- Even high degrees of reactive kerogen transformation aren't volumetrically significant since the rigid inert framework dominates

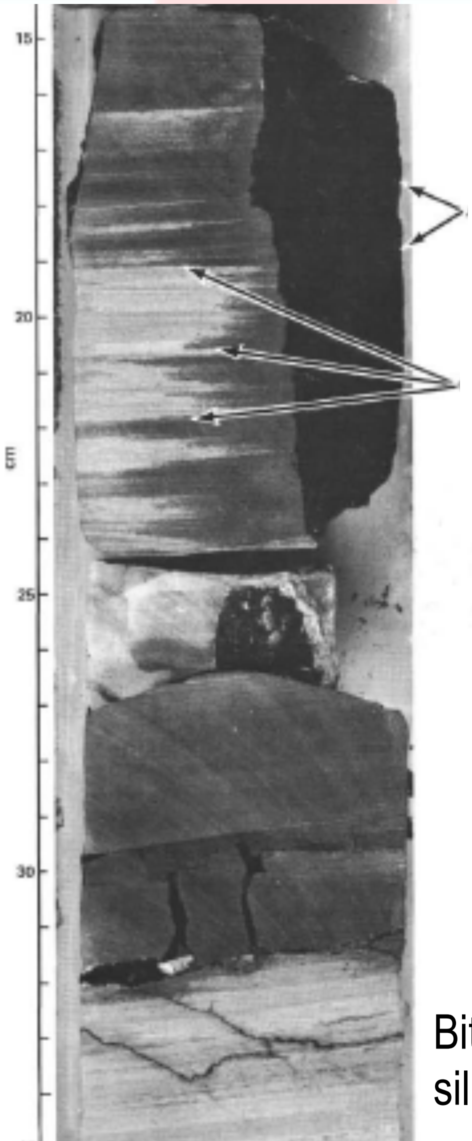
Don't confuse fluid expulsion with *OM extrusion*



Oklahoma Woodford and Arkansas Chattanooga Fms

- From a study named "Recognizing and quantifying expulsion of oil"….
- However, rocks are at a very low level of thermal stress
- High H/C and on 'diagenesis' O/C trajectory
- Low TI ($S1/C_{org}$)
  - 17-36 _wptC
- Low PC15+ EOM (EOM / C_{org})
  - 15-39 _wptC
- Low $R_o < 0.5$
- These rocks have **not expelled** a migrate-able petroleum fluid; they have **extruded** early-bituminized OM

77_DSDP 0535 core – adjacent bitumen and petroleum

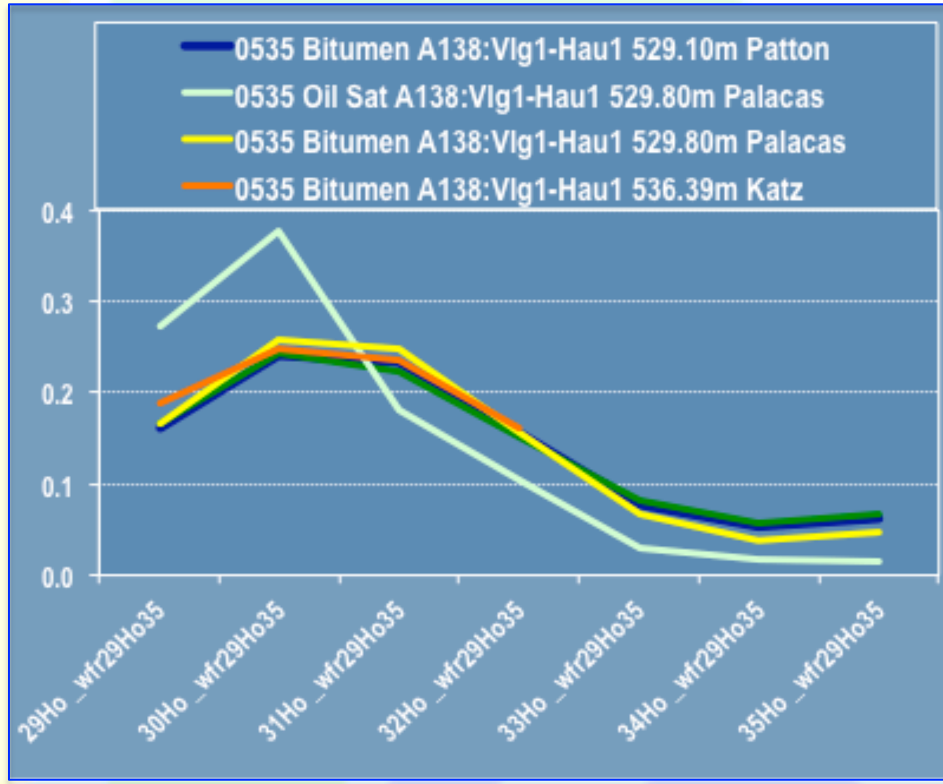


Bitumen dike – originally described as "asphalt"

Fluorescing fluid phase saturation of matrix porosity – originally described as "oil stain"

Bitumen sills

(Palacas et al 1984)

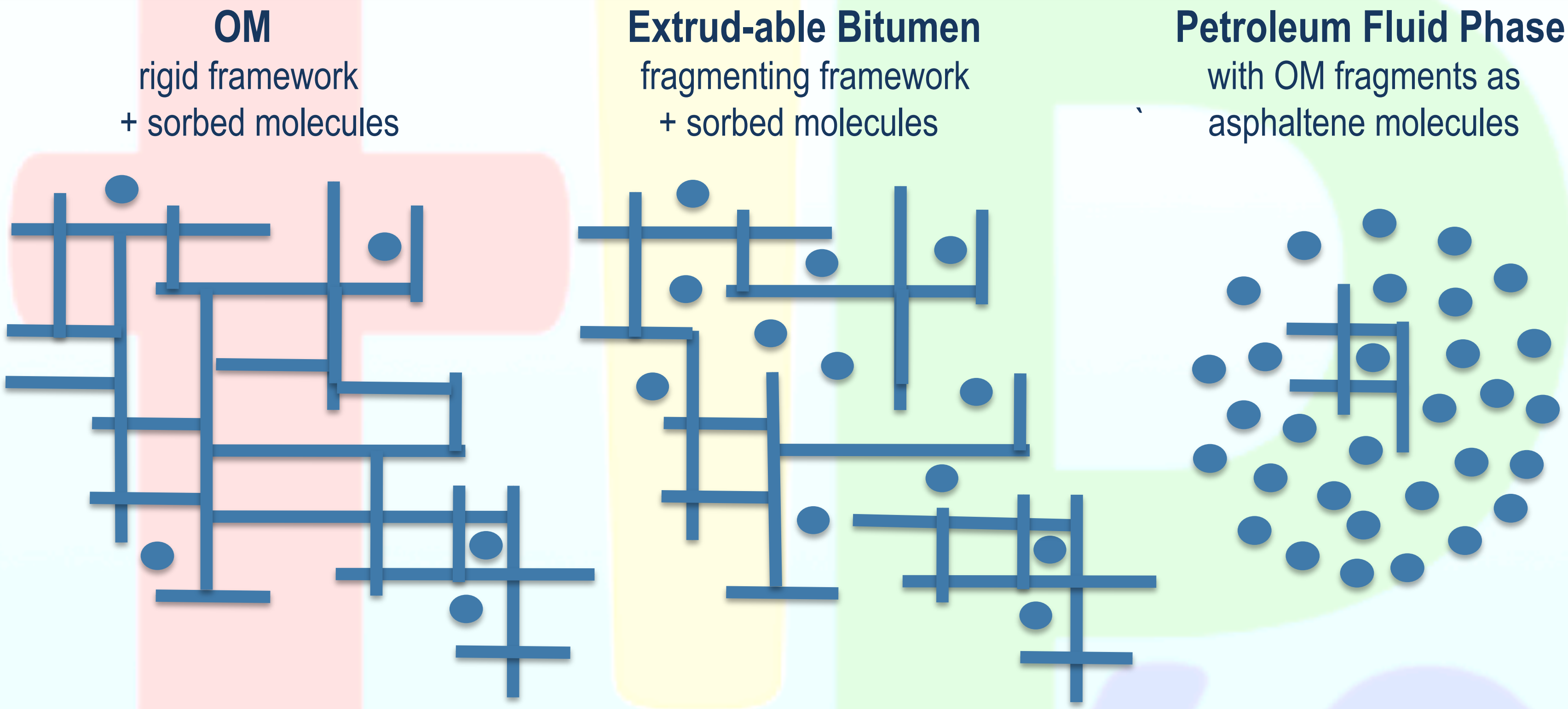


Different origins

- Bitumen has Tithonian hopane signature
- Fluid phase saturation has Oxfordian hopane signature

(Interpretation from This is Petroleum Systems, 2016)

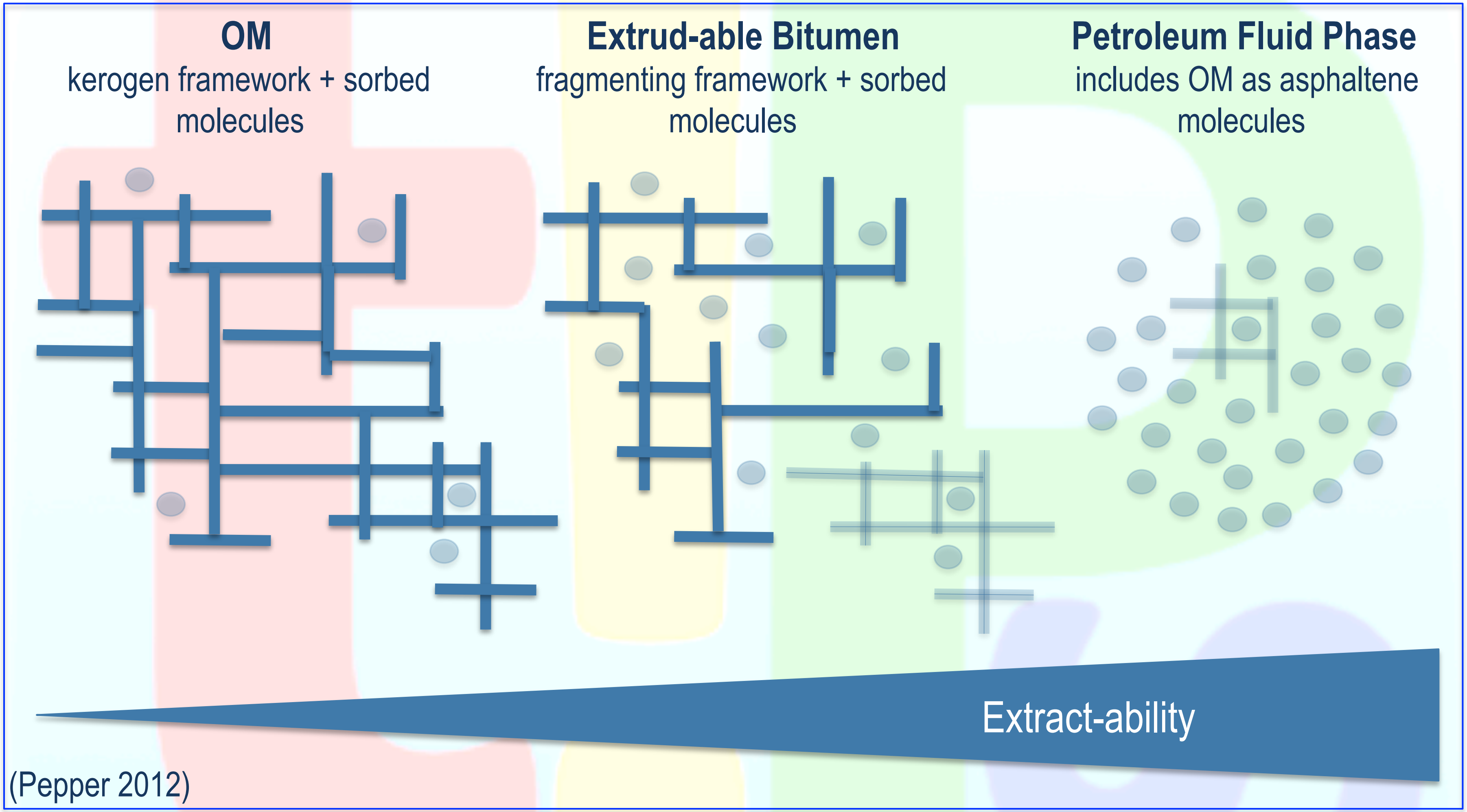
Physical changes OM-bitumen-petroleum



(Pepper 2012)

Petroleum generation induces chemical *and physical* disintegration

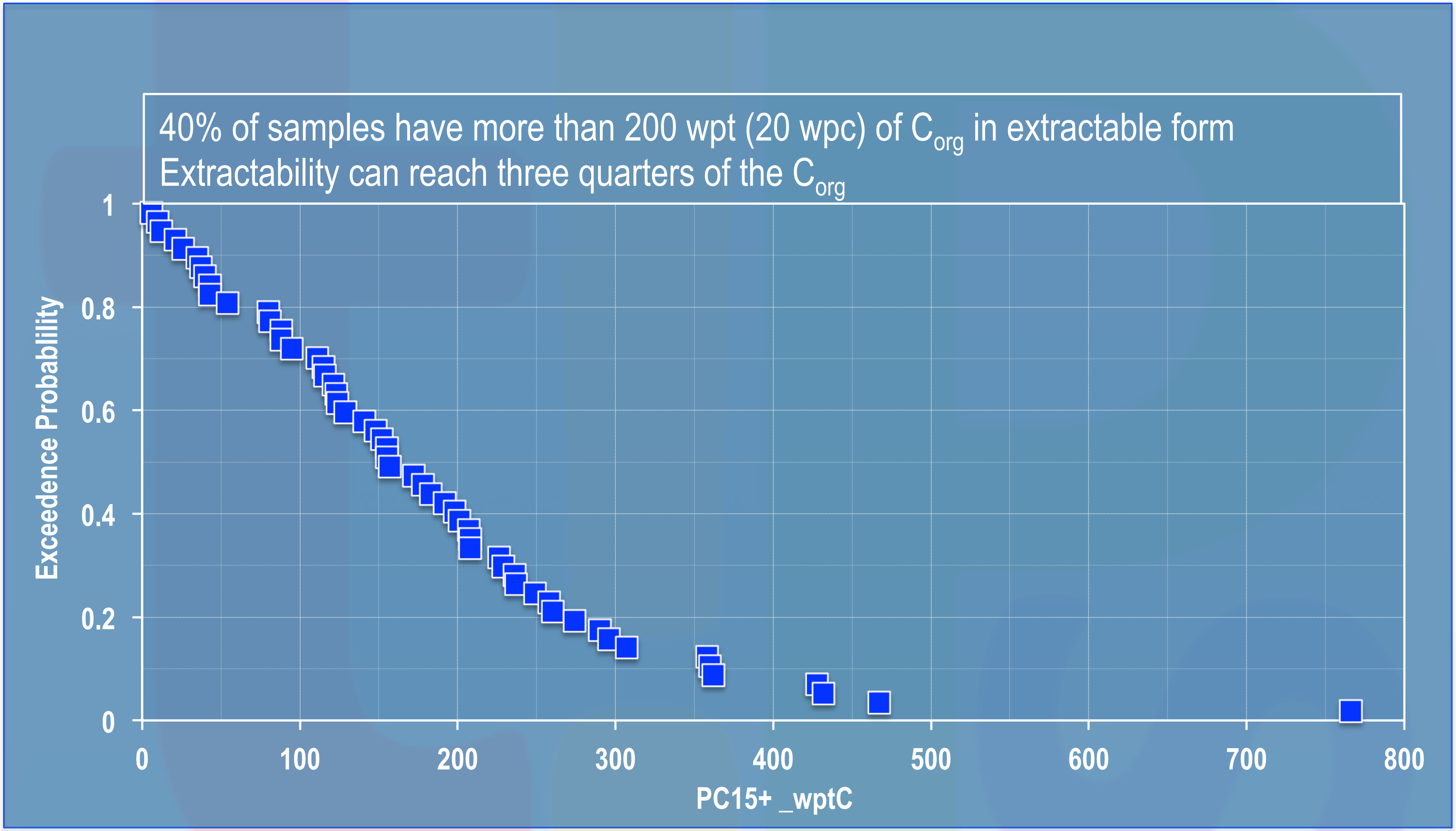
Extractability OM-bitumen-petroleum



Extractability

- Where the framework has disintegrated, can also extract significant quantities of OM fragments as asphaltenes – *N.B. Dean Stark analysis used to clean cores*

Organofacies A, high HI OM: highly extractable

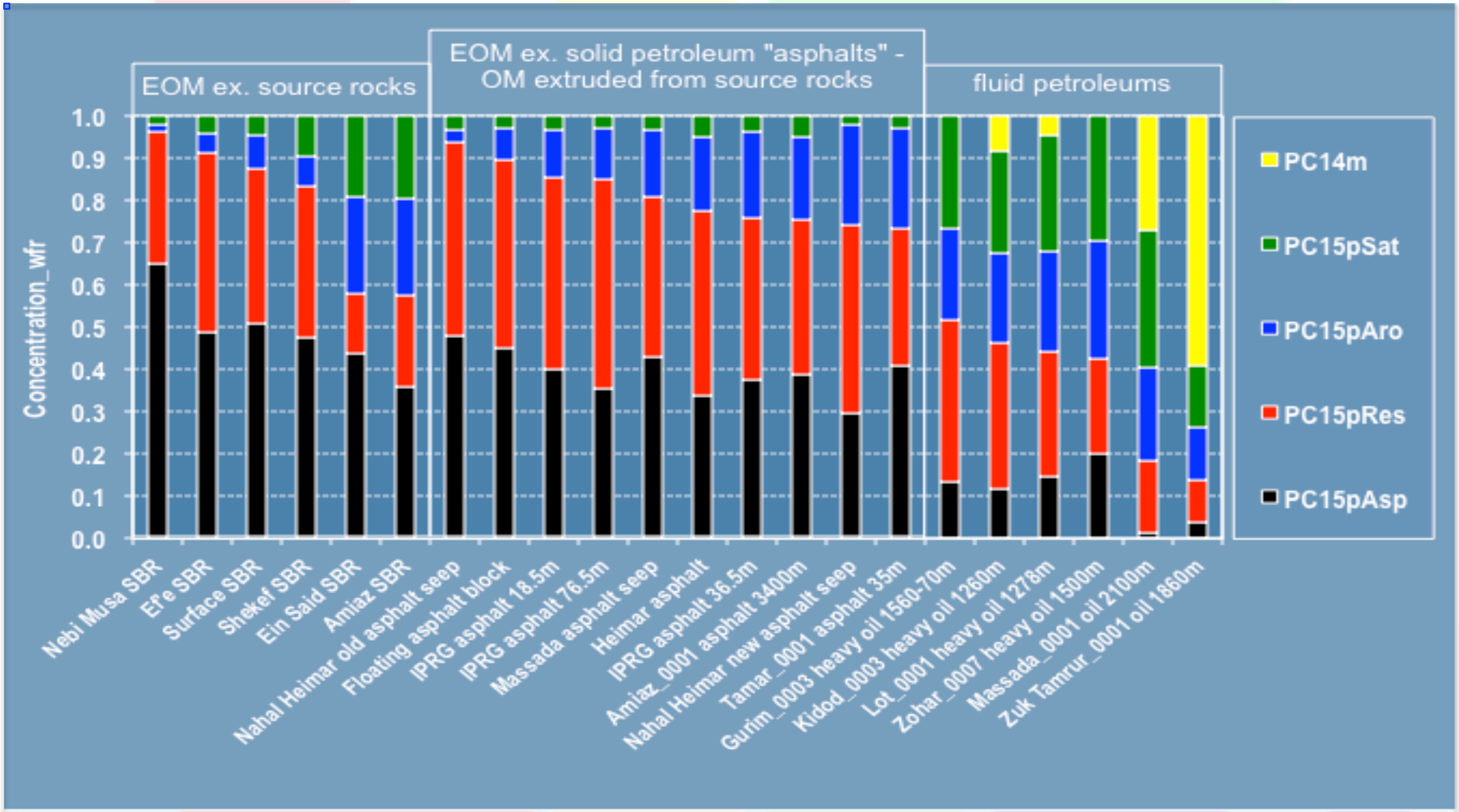


(Talukdar et al 1988)

La Luna Formation, Maracaibo Basin

- Do such high EOMs qualify as petroleum or just 'liquified OM'?

Bitumen resembles source EOM not fluid



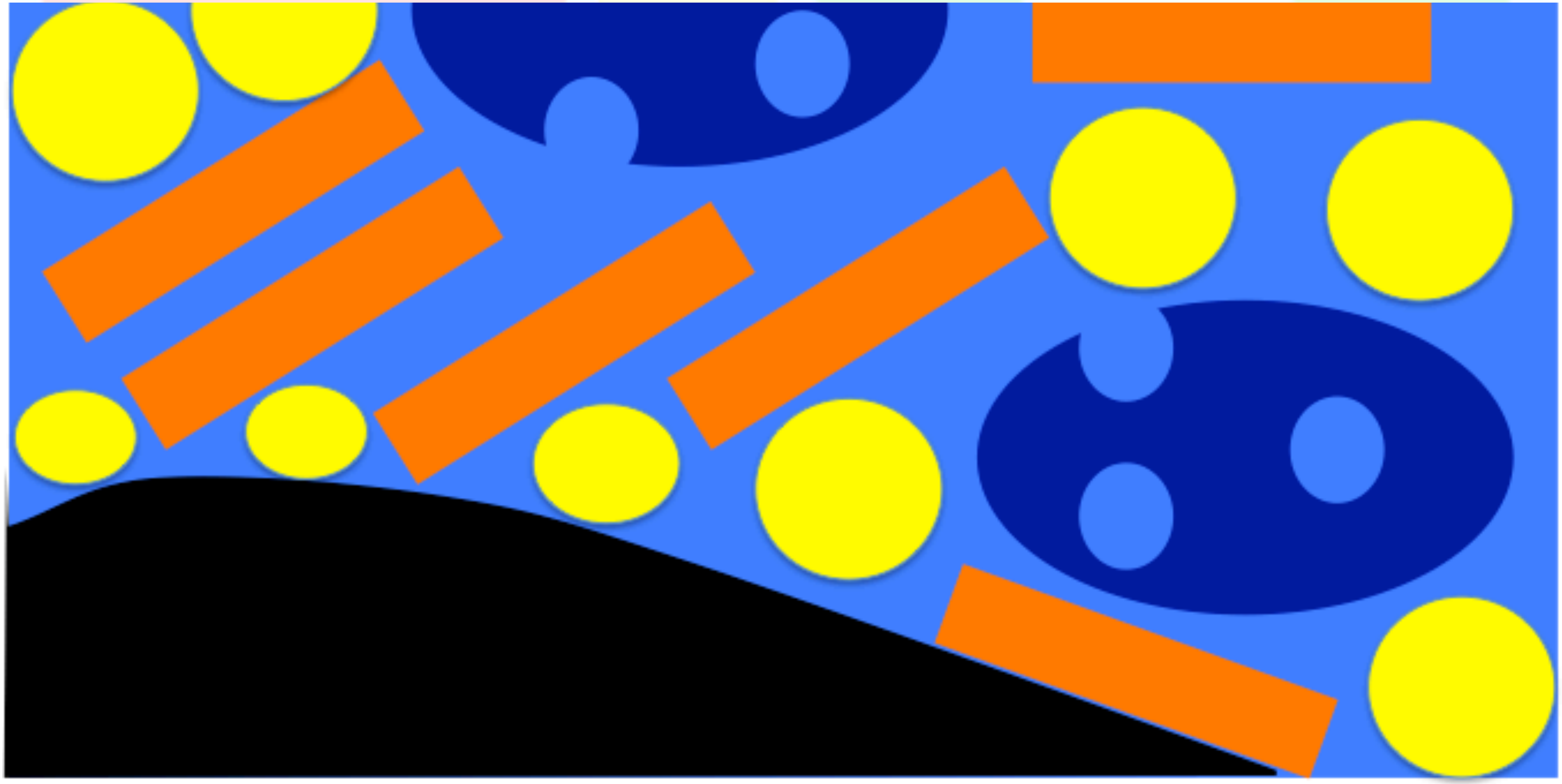
Dead Sea Basin: liquid chromatography 'SARA' data

- Similar SARA chemistry in solvent extracts from source beds and extruded bitumens
- Migrated fluid phase petroleums – including heavy oils – have different SARA

Compaction of OM - 1

Pre-oil generation – mechanical compaction of mineral and OM matrix

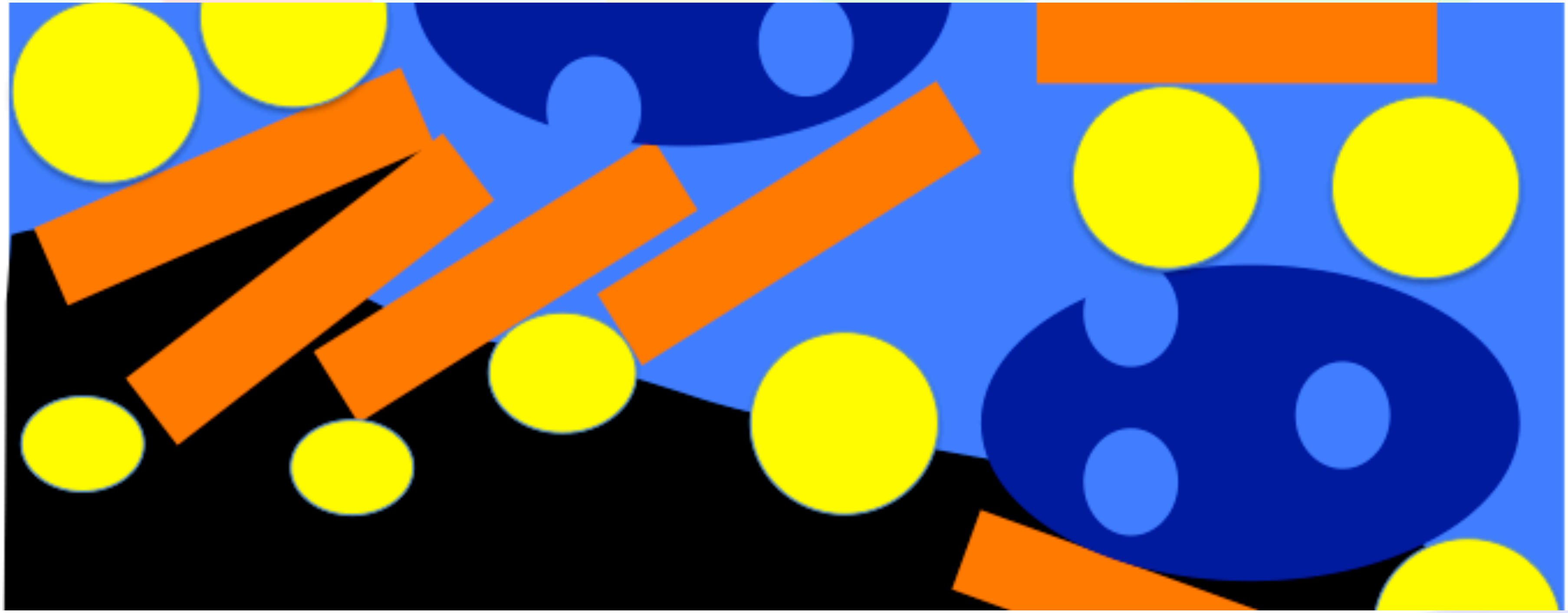
- Thermal Stress < 80 ^{o}C; PI < 0.05 – de-watering



Compaction of OM - 2

Early oil generation – pre-expulsion

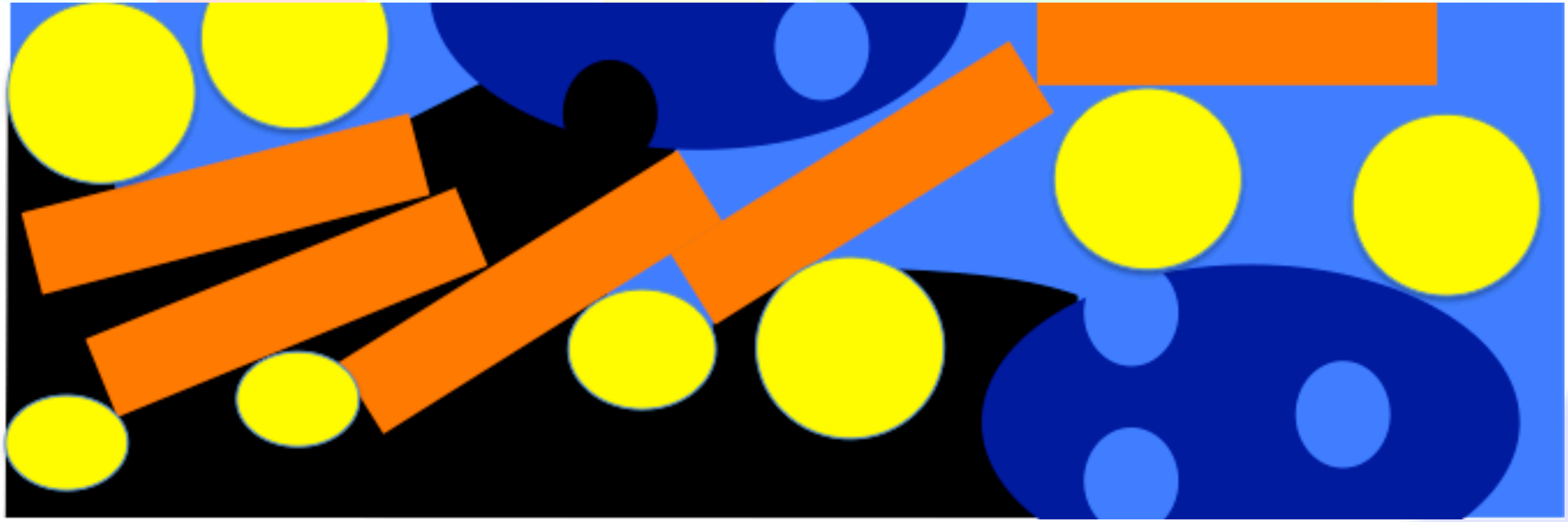
- STS ~ 80-100 ^{o}C – lowest for high sulfur Organofacies A OM
- PI ~ 0.05-0.20 – maturing but pre-expulsion
- Hess (Huang et al 2008 and Han et al 2010) data on bitumen dykes/sills in GoM sub-salt Stampede field shows softening point as low as 70 ^{o}C



Compaction of OM - 3

Oil generation – expulsion window

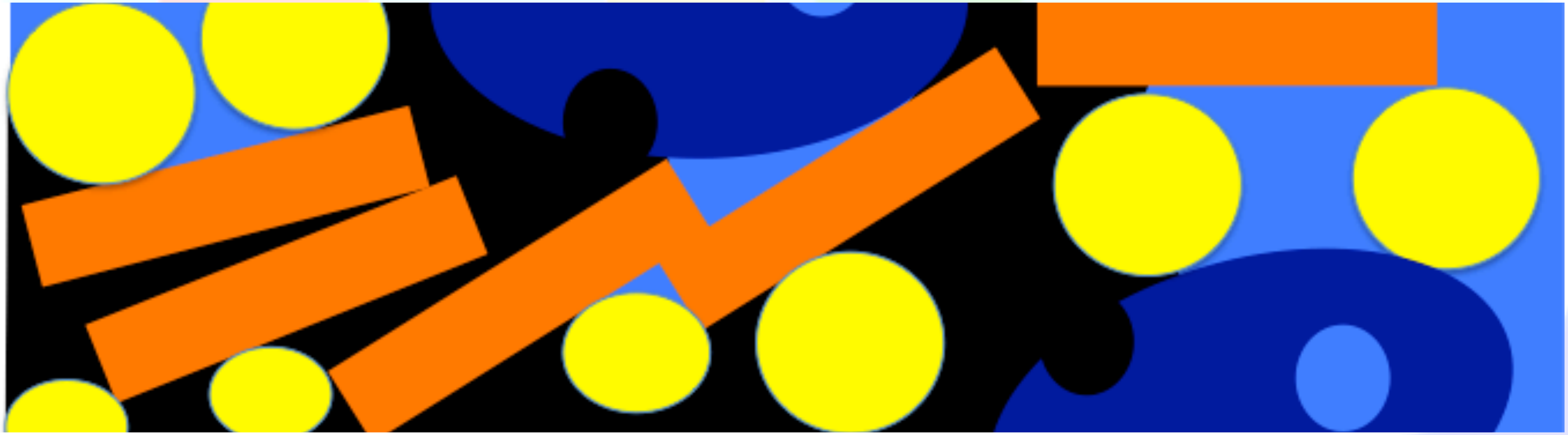
- STS > 100 ^{o}C – lowest for high sulfur Organofacies A OM
- PI > 0.15-0.20 – maturing further and expelling
- Extruded OM may be leaving the source bed at this stage via dikes. Hess data show bitumen extruded at ~ 110 ^{o}C STS



Compaction of OM - 4

Oil-gas window transition

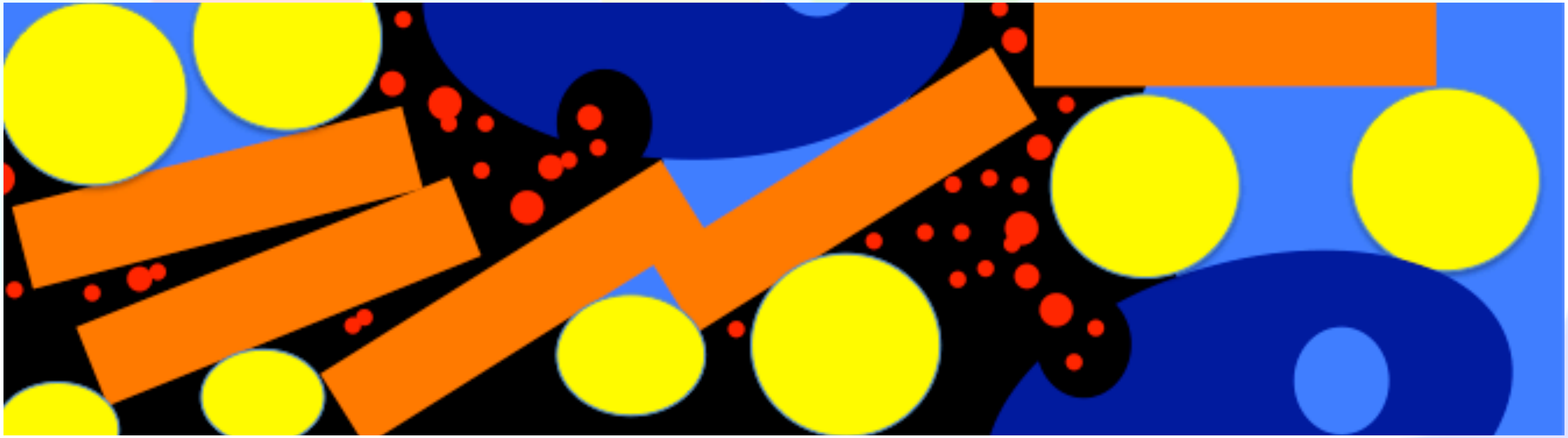
- STS ~ 150 ^{o}C
- Bituminized and residual ‘mechanically sifted’ OM now in sheltered locations
- Mineral matrix framework much more rigid



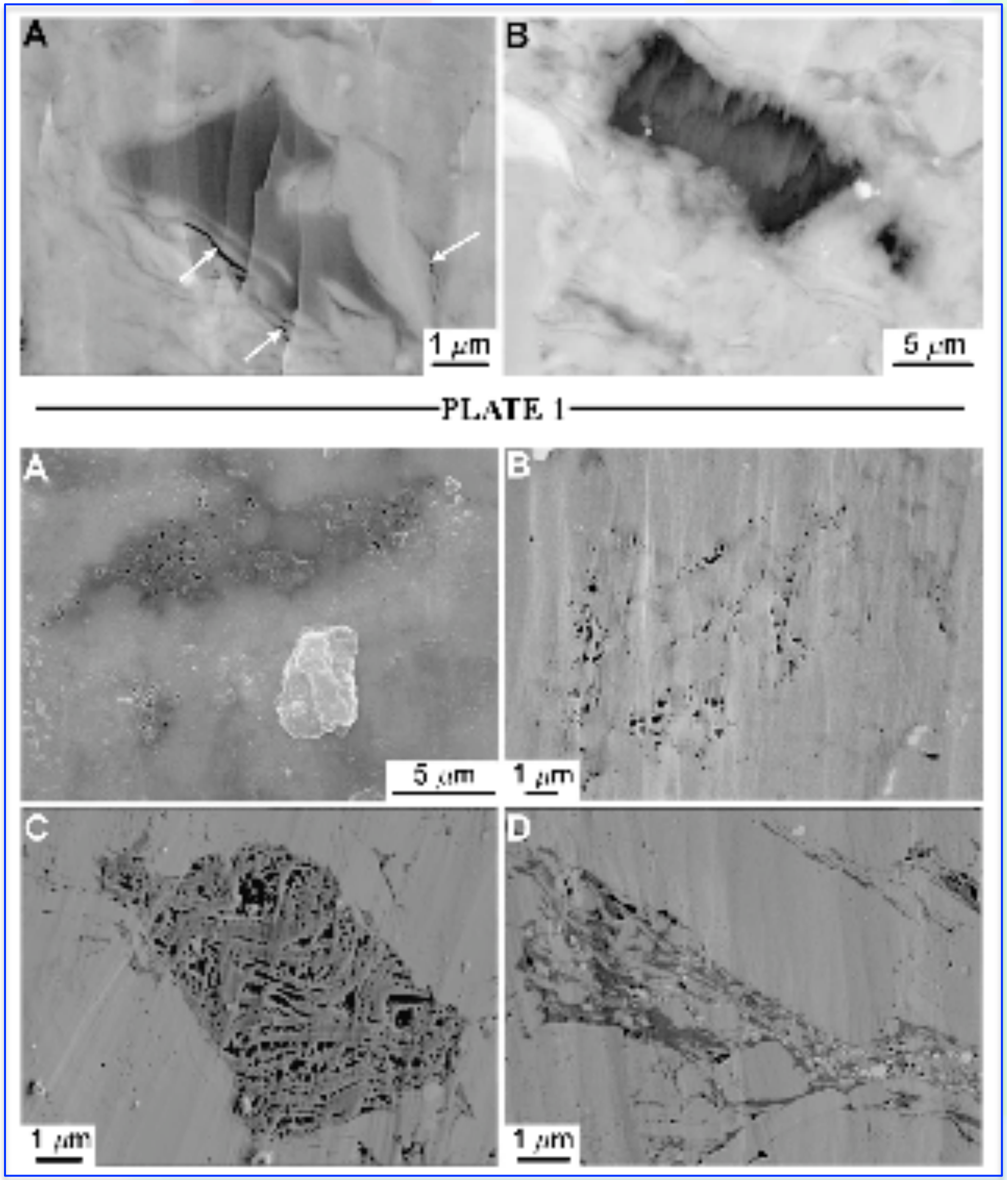
Compaction of OM - 5

Gas window

- STS > 150 ºC
- **Unloaded OM can now develop organic porosity** from gas-generating kerogen plus cracking of oil molecules sorbed in the OM matrix



Where does the bituminized OM go?



'Oil window' maturity

- Compared to the original OM fragments, shapes and sizes of OM are much smaller and more irregular; pore filling
- The bituminized, ductile OM has already been fragmented by squeezing into increasingly protected (less load bearing) positions

'Gas window' maturity

- Unloaded OM can now develop porosity without further compaction

Mechanical 'sifting'

- More labile components of the OM will weaken and be mobilized first, separating from the developing inert carbon reside
- Analog: salt can leave other evaporites behind during loading

SEM images from Loucks 2009

Terminology is important

Can we stop speaking *'Klingon'* to each other?

Summary: bitumen terminology

Alternate term for: *pre-oil bitumen*

- OM in high-HI rocks has little inert carbon: bond-breaking during early generation, especially in Organofacies A OM, weakens it
- The OM can be extruded wholesale under the overburden stress as a non-newtonian fluid. This is NOT petroleum migration!

= Bitumen

Alternate term for: *post-oil bitumen / pyrobitumen*

- Carbonaceous residue resulting from hydrogen balance limitations during cracking of petroleum carbon compounds

= Coke

Alternate term for *traditional geochemist's bitumen extract*

- Petroleum extracted from OM using a solvent

= **EOM**