An Introduction to Wettability of Oil Reservoirs

Petrophysics and Surface Chemistry Group

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Outline

- The big picture
- Microscopic view of oil reservoirs
- Capillary phenomena
- Surface chemistry in oil reservoirs

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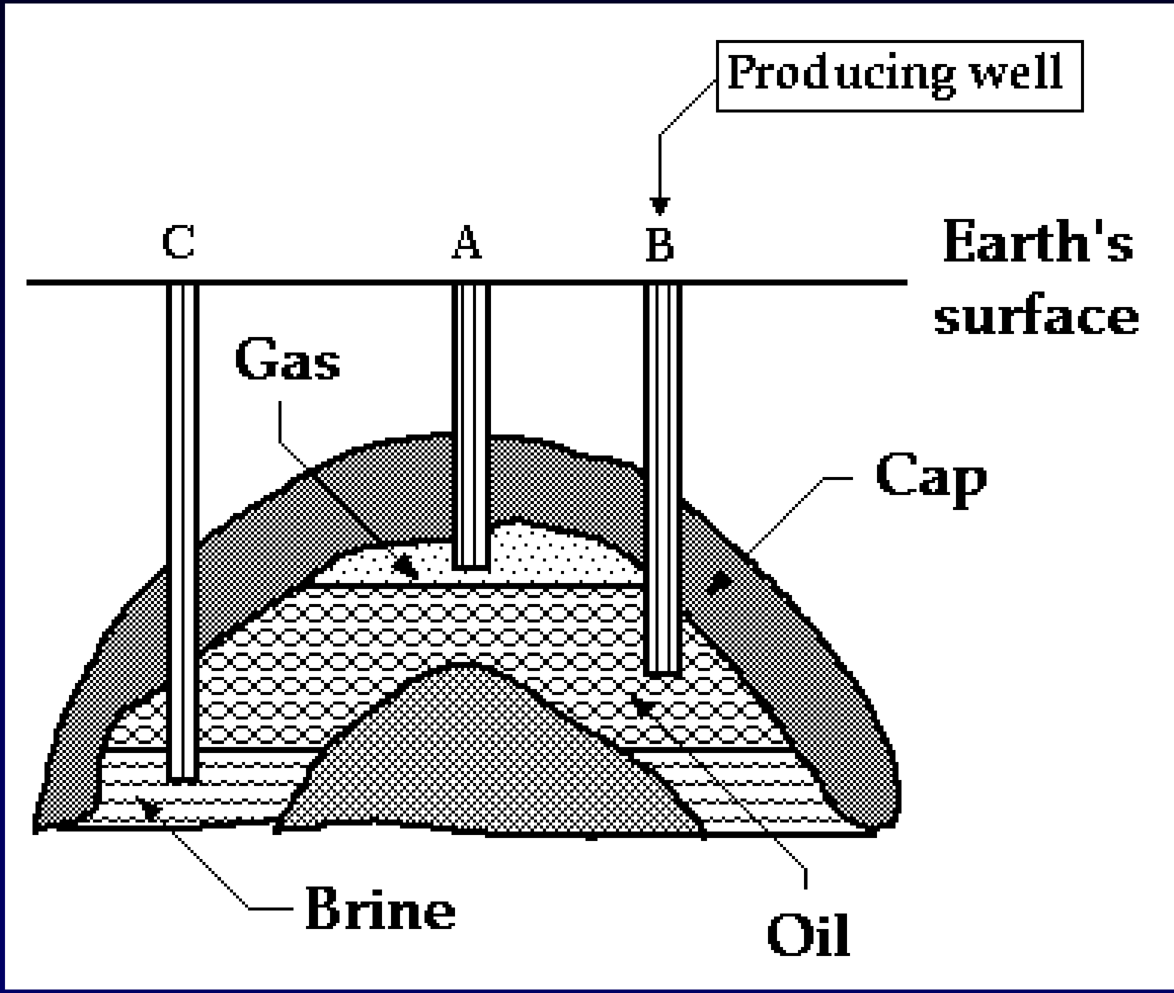
Geologic scale

Structural trap



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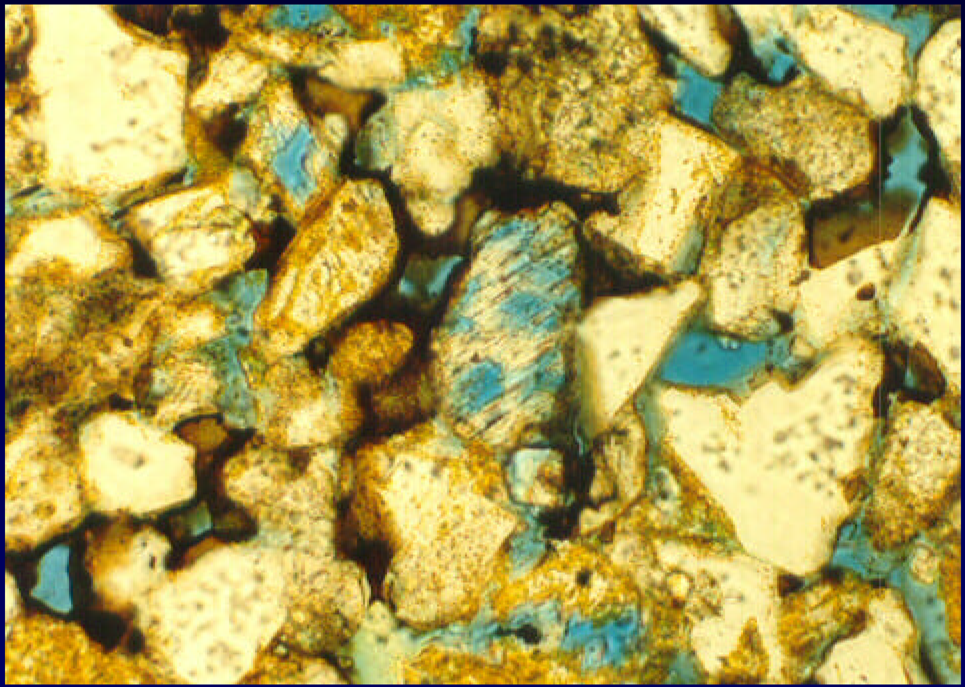
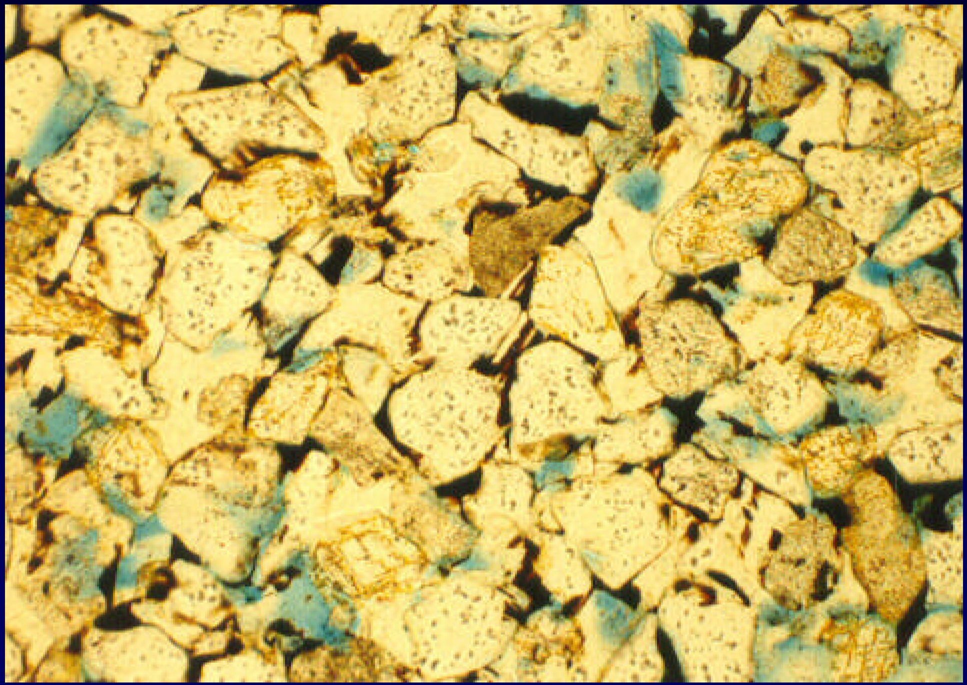
Microscopic view of an oil reservoir

Typical sandstone.

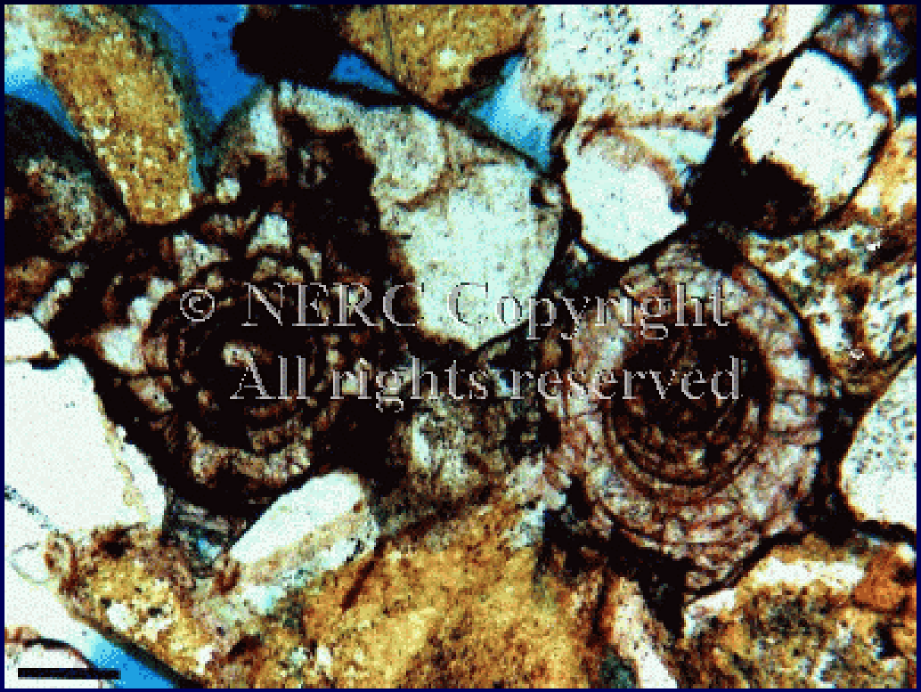


Blue color is epoxy in interconnected pore spaces.

Less porous or less permeable?



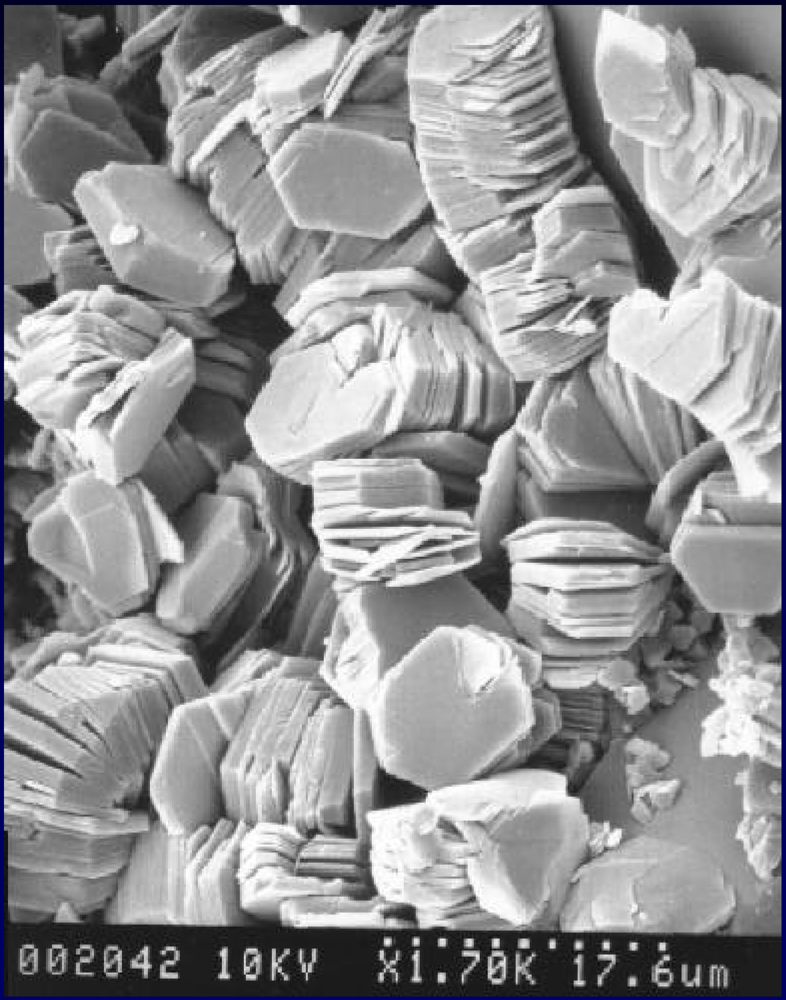
More complicated sandstone



Early diagenetic spheroids in a fine- to medium-grained subarkose, showing variations in internal patterns and typical radial-fibrous texture.
St Bees Sandstone Formation (Triassic), Cumbria, UK.
White - quartz; yellow - stained K-feldspar; brown - iron oxide; blue - stained porosity.
Scale bar: 100 microns.

from: STRONG, G. E. & PEARCE, J. M. 1995. Carbonate spheroids in Permo-Triassic sandstones of the Sellafield area, Cumbria. Proceedings of the Yorkshire Geological Society Vol. 50, Pt 3, 209-211.

Kaolinite (clay)



Authigenic kaolinite, Carter sandstone, Black Warrior basin, Alabama

Kugler, R.L. and Pashin, J.C., 1994, Reservoir heterogeneity in Carter sandstone, North Blowhorn Creek oil unit and vicinity, Black Warrior basin, Alabama: Geological Survey of Alabama Circular 159, 91 p.

Illite (clay)

"Hairy" illite clay found in the Coconino sandstone - 2000X — The fine hair-like structure is actually crystalline mineral and is a diagenetic alteration product of other minerals in the subsurface.

http://www.creationresearch.org/vacrc/sem02.html

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Common characteristics of oil-bearing rocks

- Pores in which oil is found are small

  $d < 100\mu$

- Surface area is high

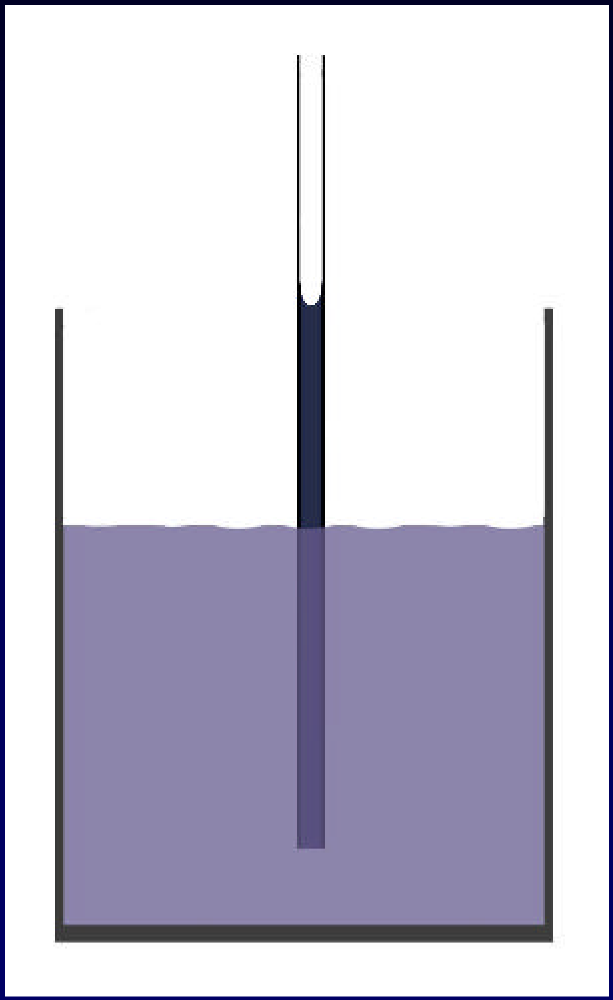
  $>> 1\ m^2/g$

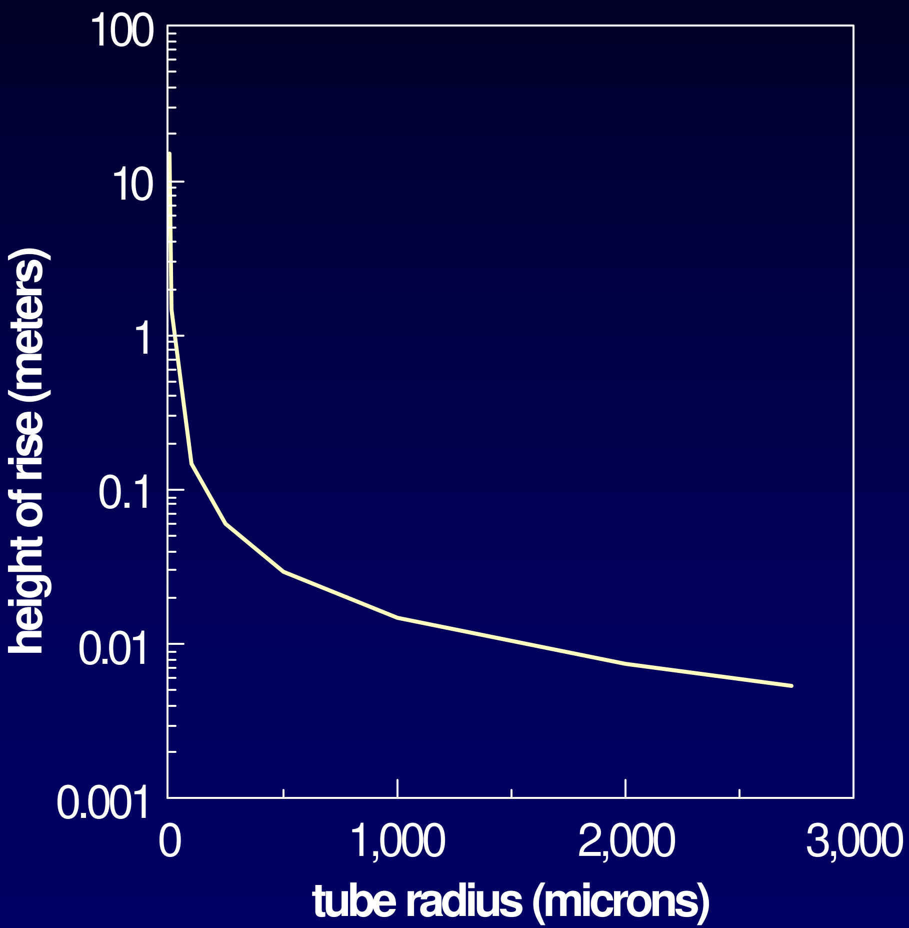
- Fluid-fluid interfaces coexist.
- Capillary forces hold oil in place.

Capillary phenomena

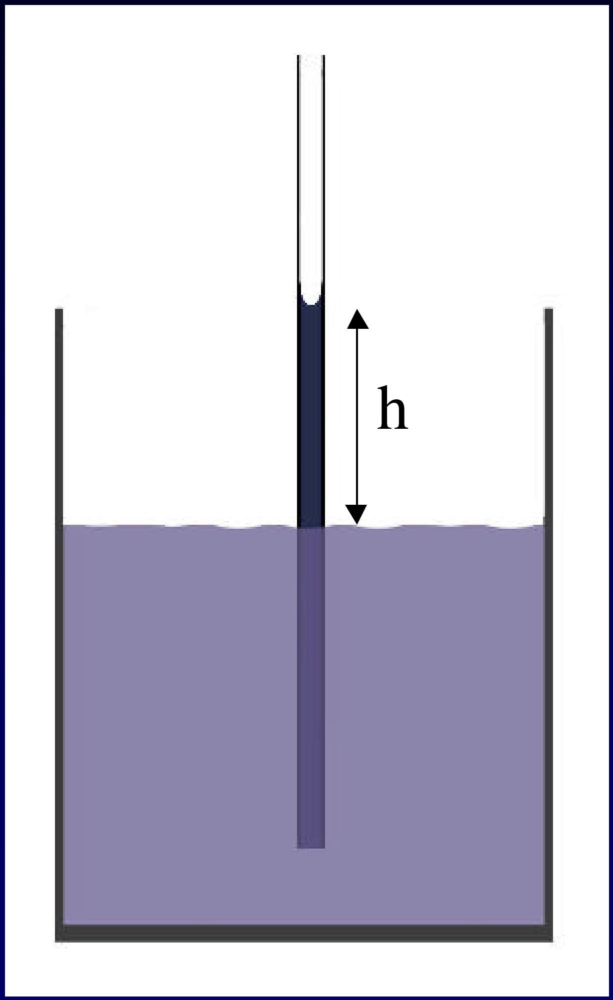
- Capillary rise
- Capillary pressure
- Interfacial tension
- Contact angles

Capillary rise





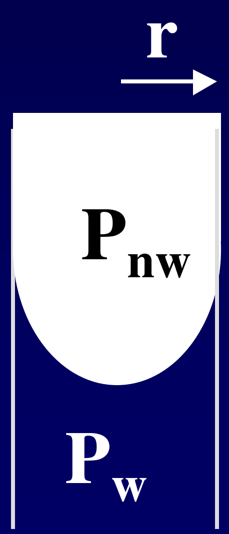
Capillary pressure



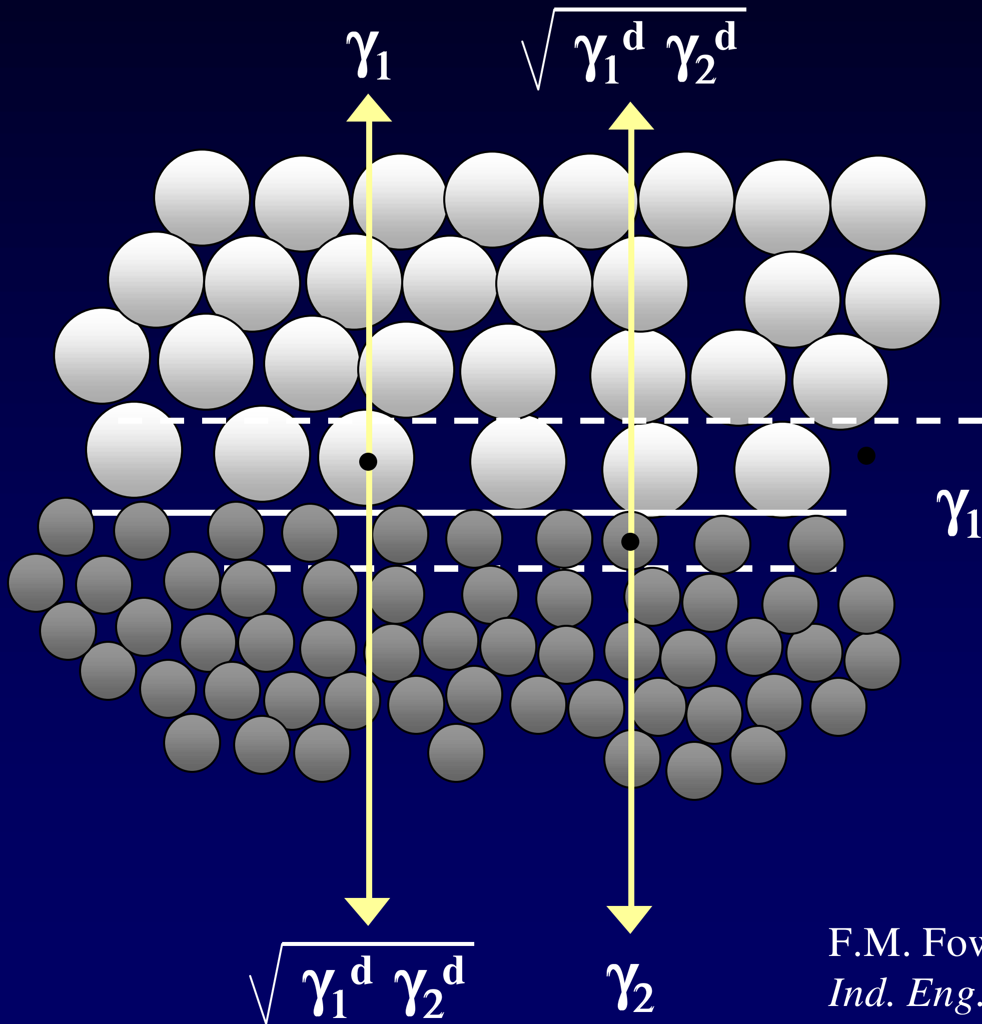
$$P_c = \Delta\rho\, g\, h$$

$$P_c = 2\gamma / r$$

$$P_c = P_{nw} - P_w$$



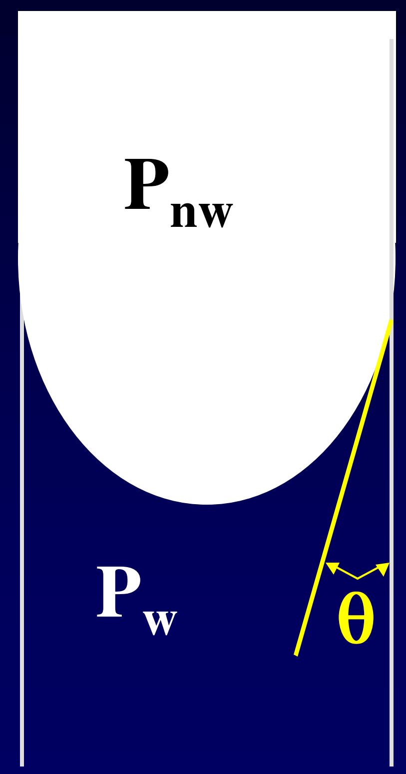
Interfacial tension, γ



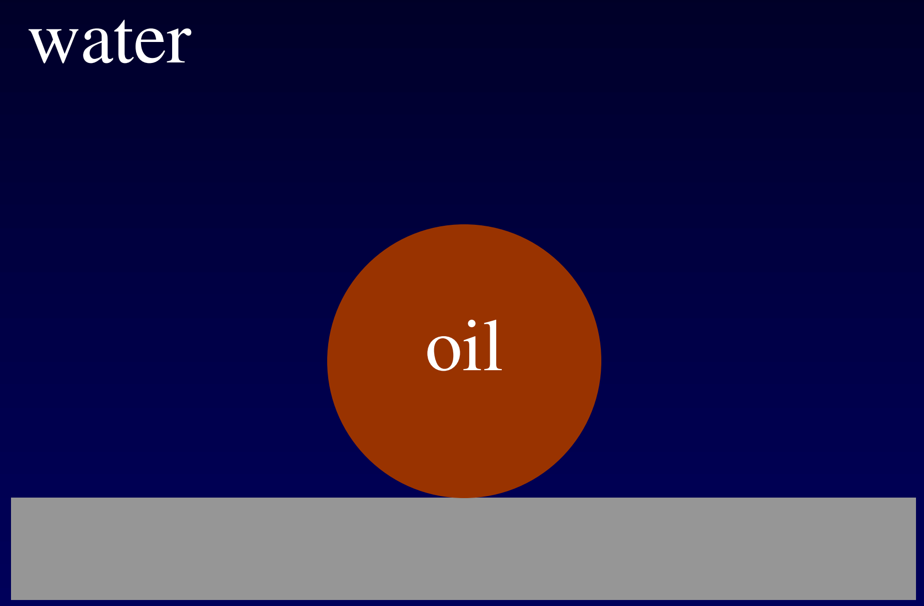
$$\gamma_{12} = \gamma_1 + \gamma_2 - 2\sqrt{\gamma_1^d \gamma_2^d}$$

F.M. Fowkes, "Attractive Forces at Interfaces," *Ind. Eng. Chem.* (Dec 1964) **56**, 40-52.

Why is this interface curved?

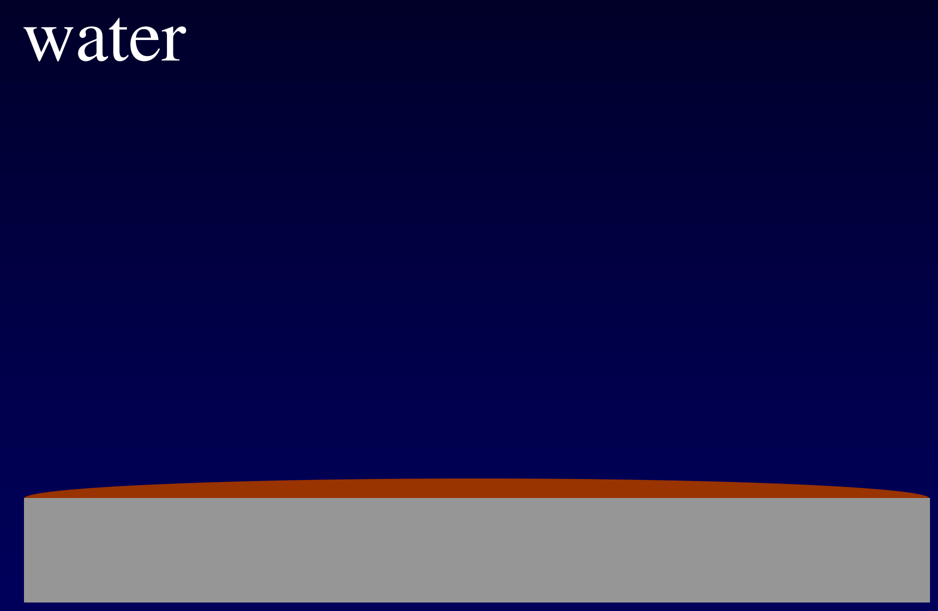


Water-wet (oil is non-wetting)



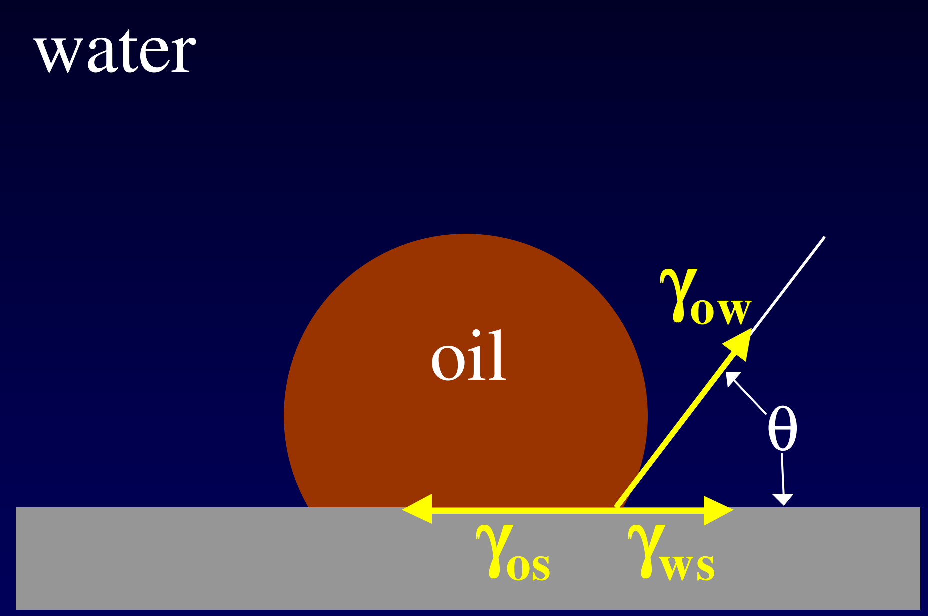
$$\theta = 0°$$

Oil-wet (oil is spreading)



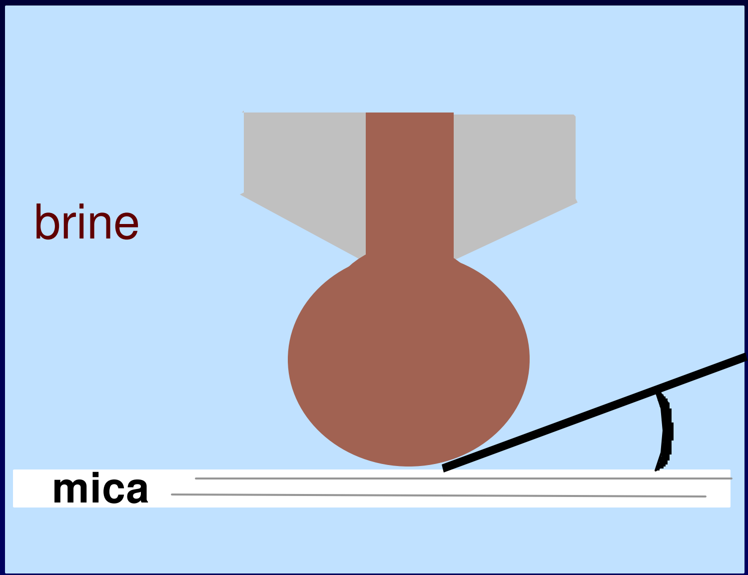
$\theta = 180°$

Partial wetting: 0° < θ < 180°

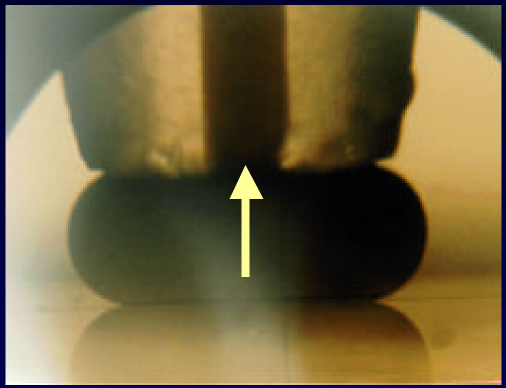


$$\gamma_{os} = \gamma_{ws} + \gamma_{ow} \cos \theta$$

Crude oil contacting a clean surface



Adhesion of crude oil under brine



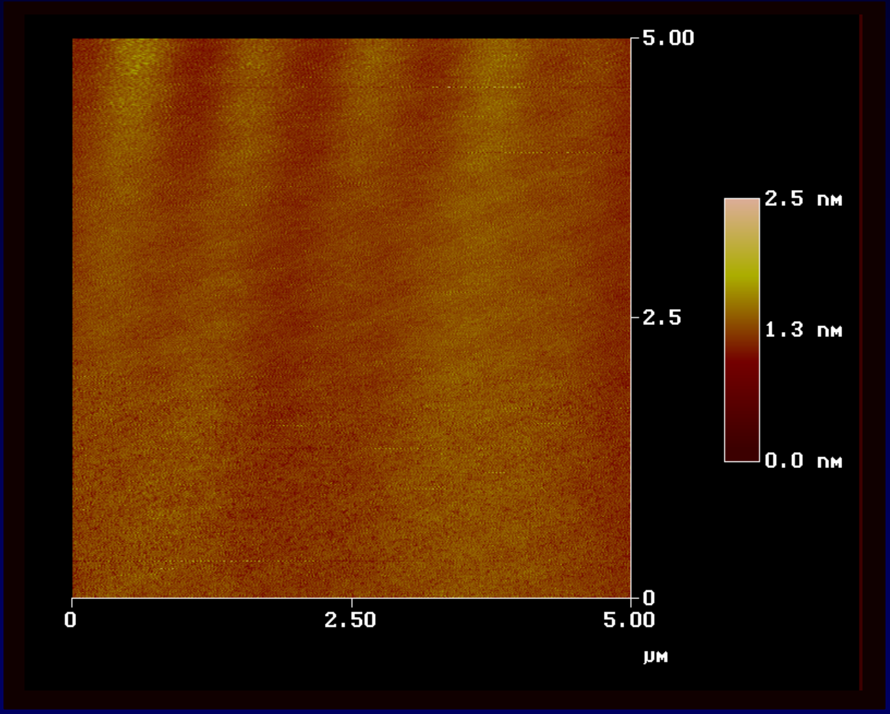
A fresh drop of crude oil under water does not wet the surface.

After it contacts the surface, the area under the drop can become oil-wet.

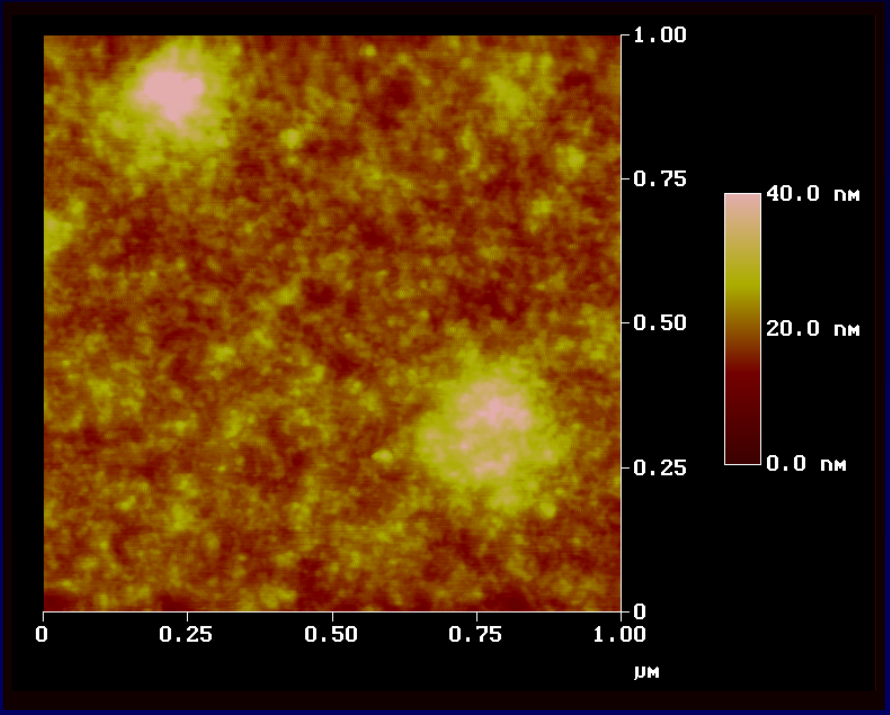
If so, a drop of crude oil remains adhering to the surface.

AFM shows adsorption

clean mica

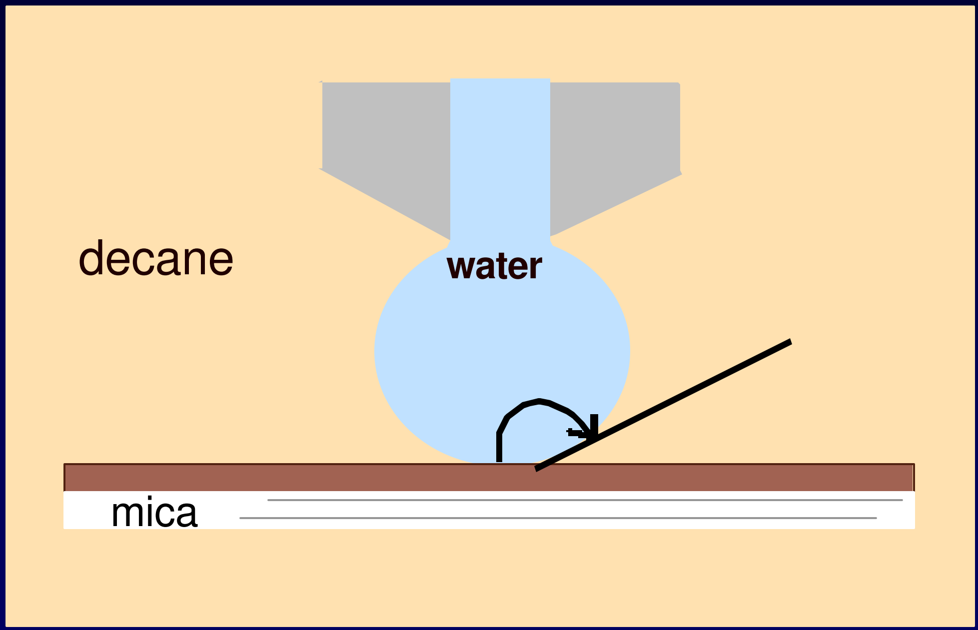


A-93 treated mica

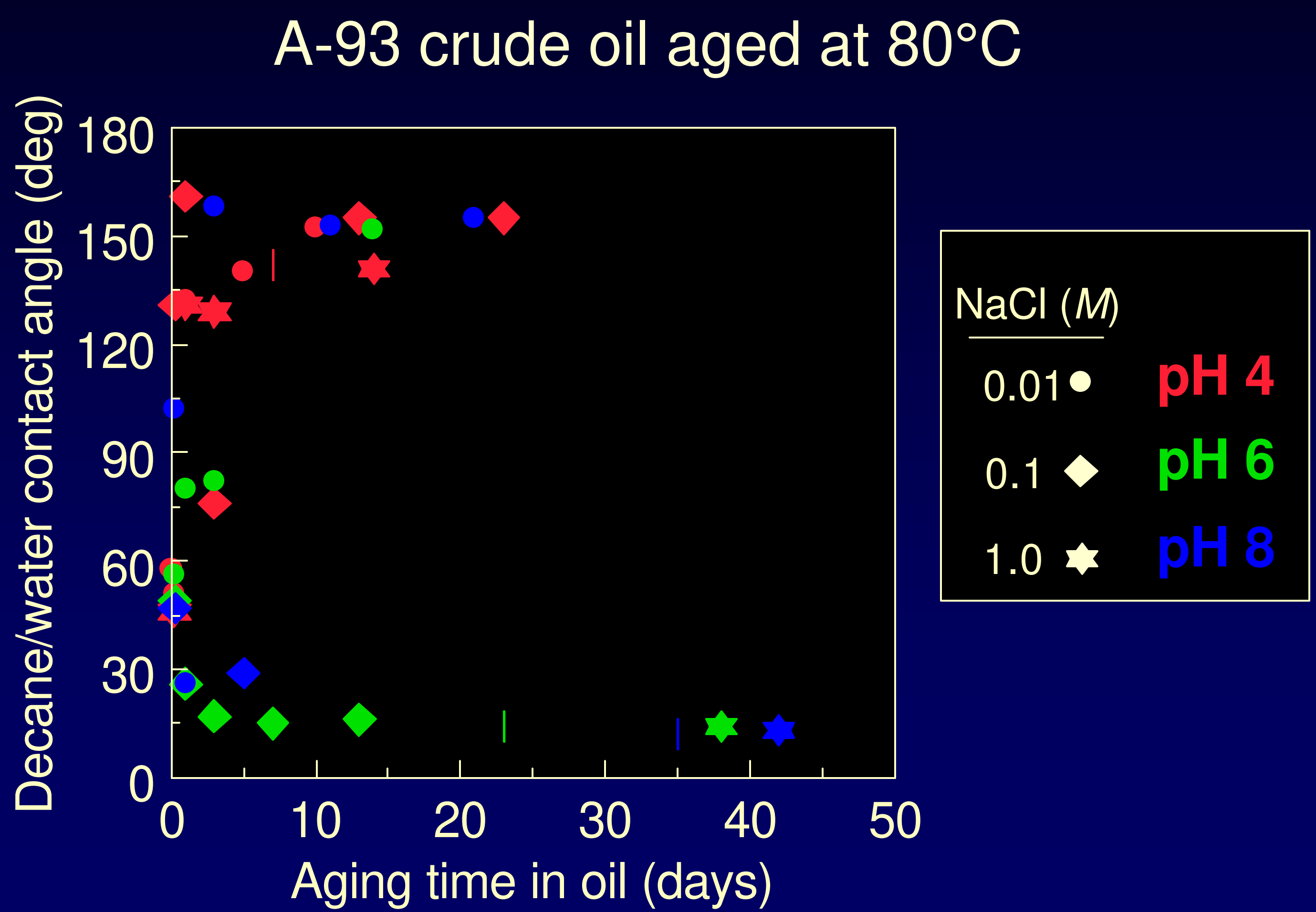


PB brine + A-93, 3 weeks, 80°C,
wash with cyclohexane

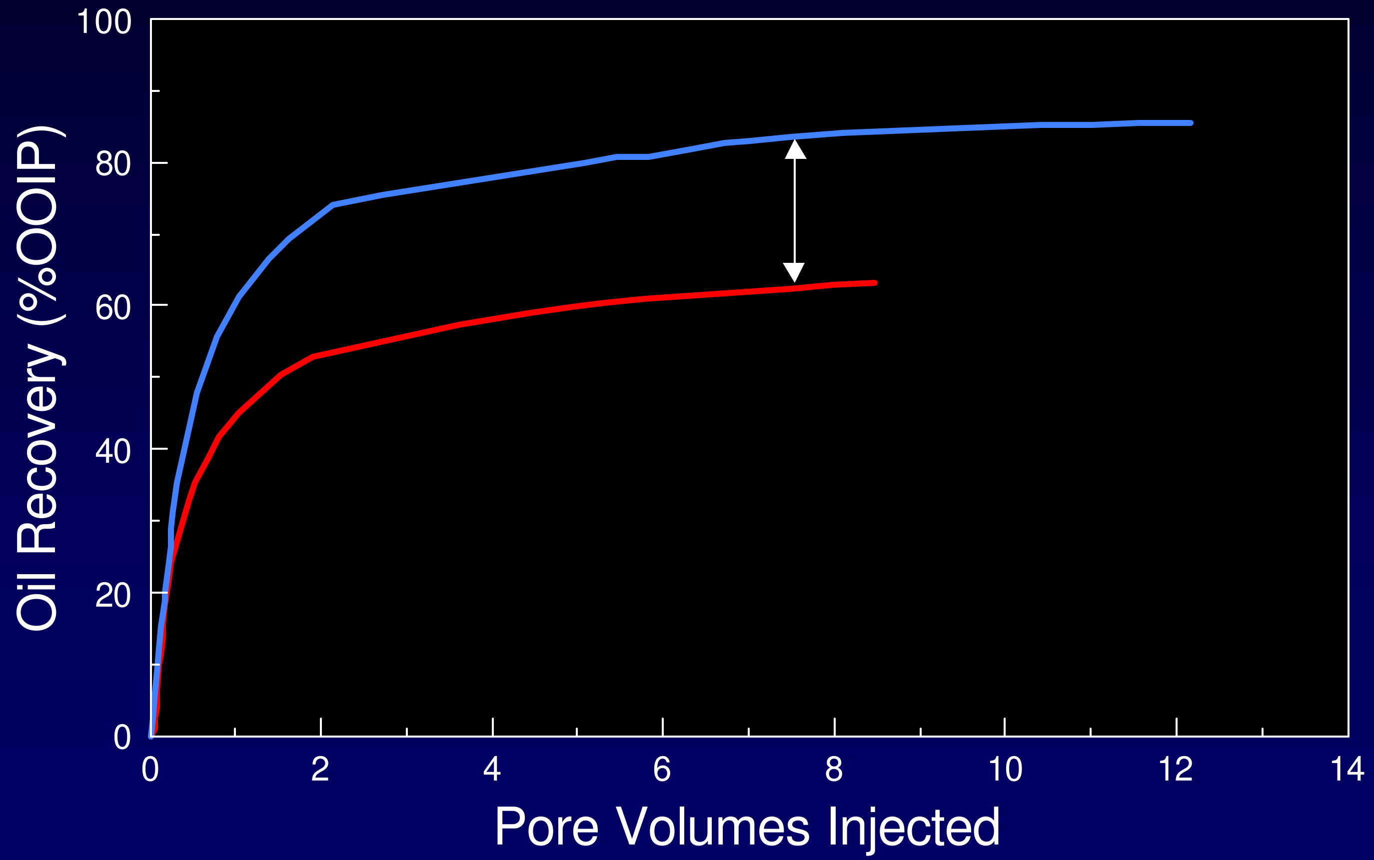
Contact angle on treated surface



Brine mediates crude oil/solid interactions



Wettability affects oil recovery



Wettability of an oil reservoir?

- There is not one simple answer.
- Measure properties of reservoir cores
  - preserved in original condition
  - restored to original condition
- Consider the underlying surface chemistry.

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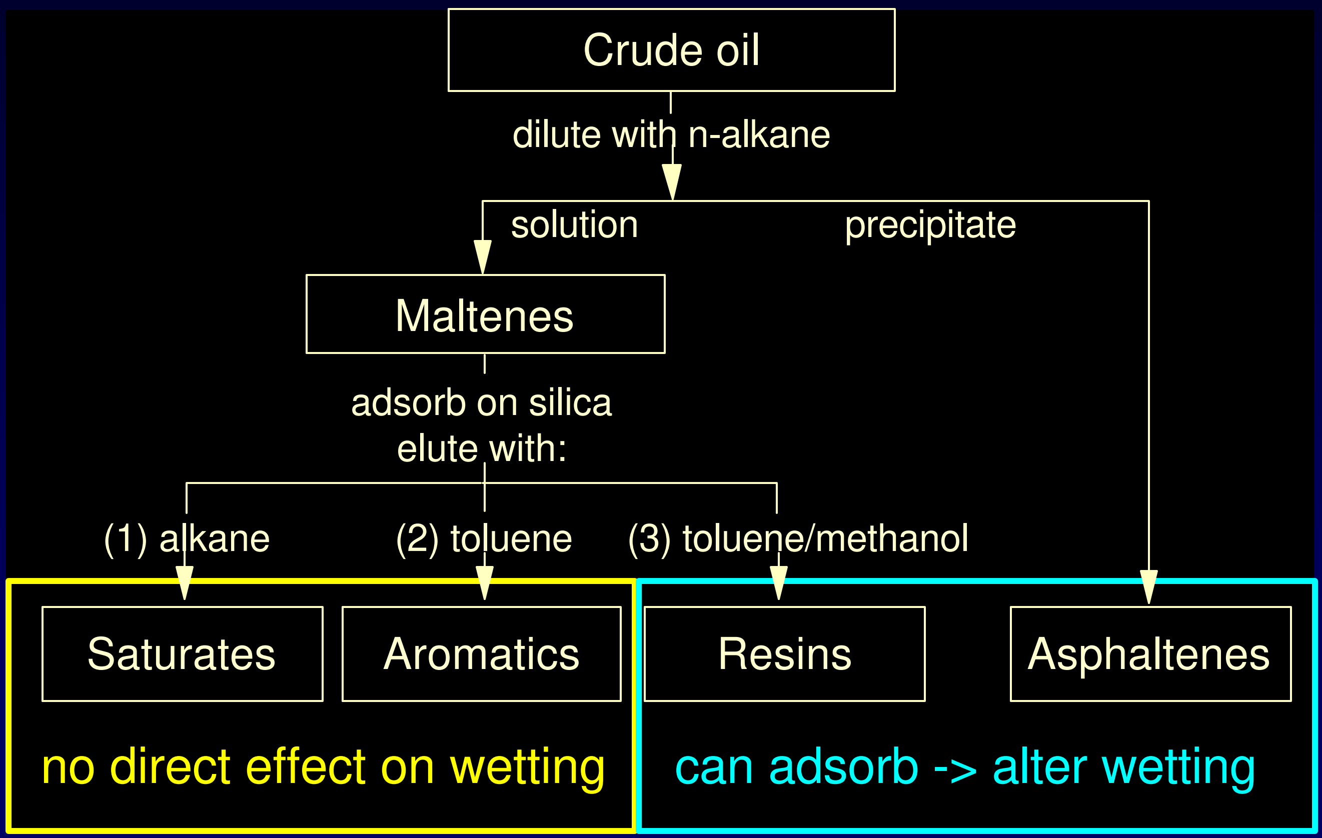
Crude oil fractions



Mechanisms of interaction

- Polar (water absent)
- Ionic (water present)
  - acid/base
  - ion binding
- Surface precipitation

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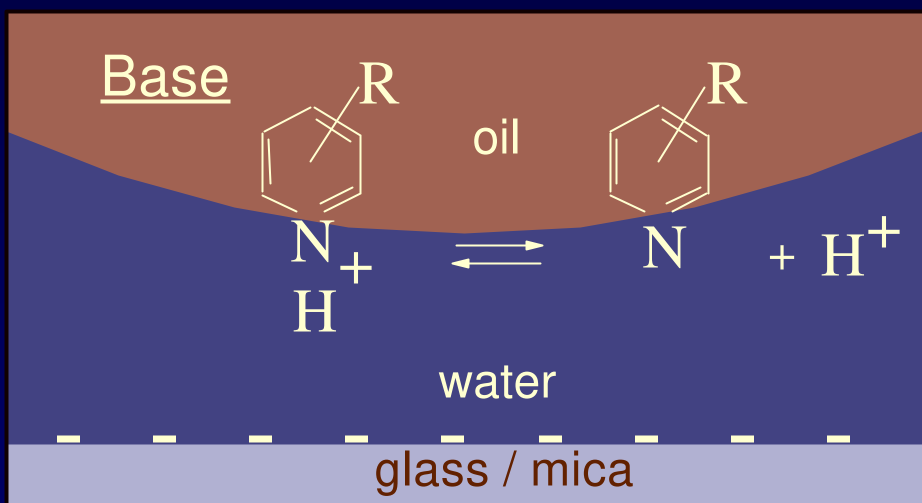
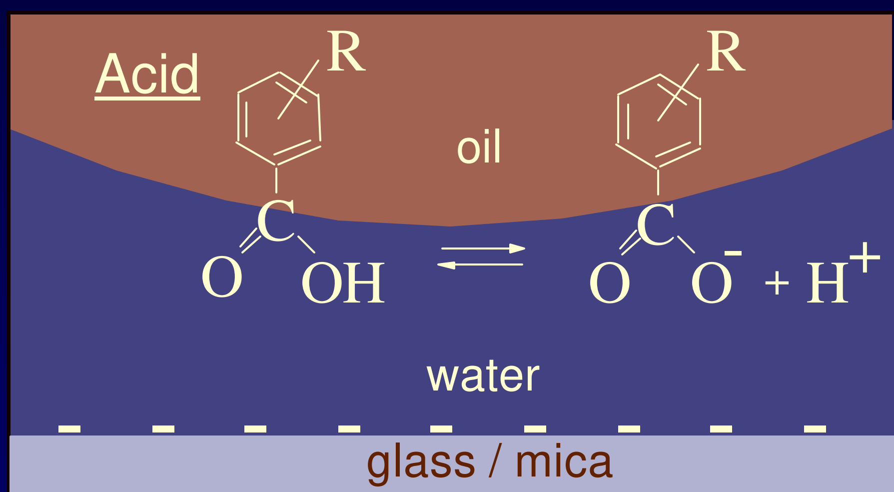
Basic oil components

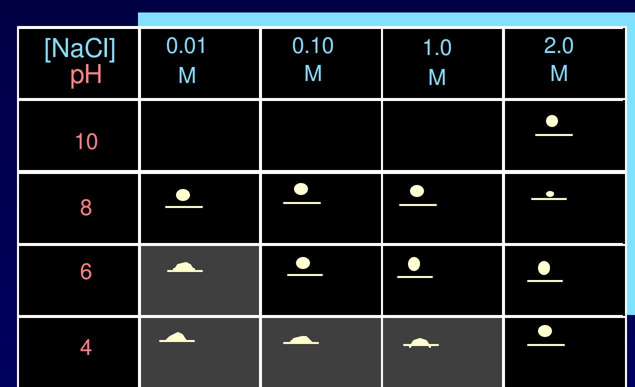
low pH ⟶ high pH



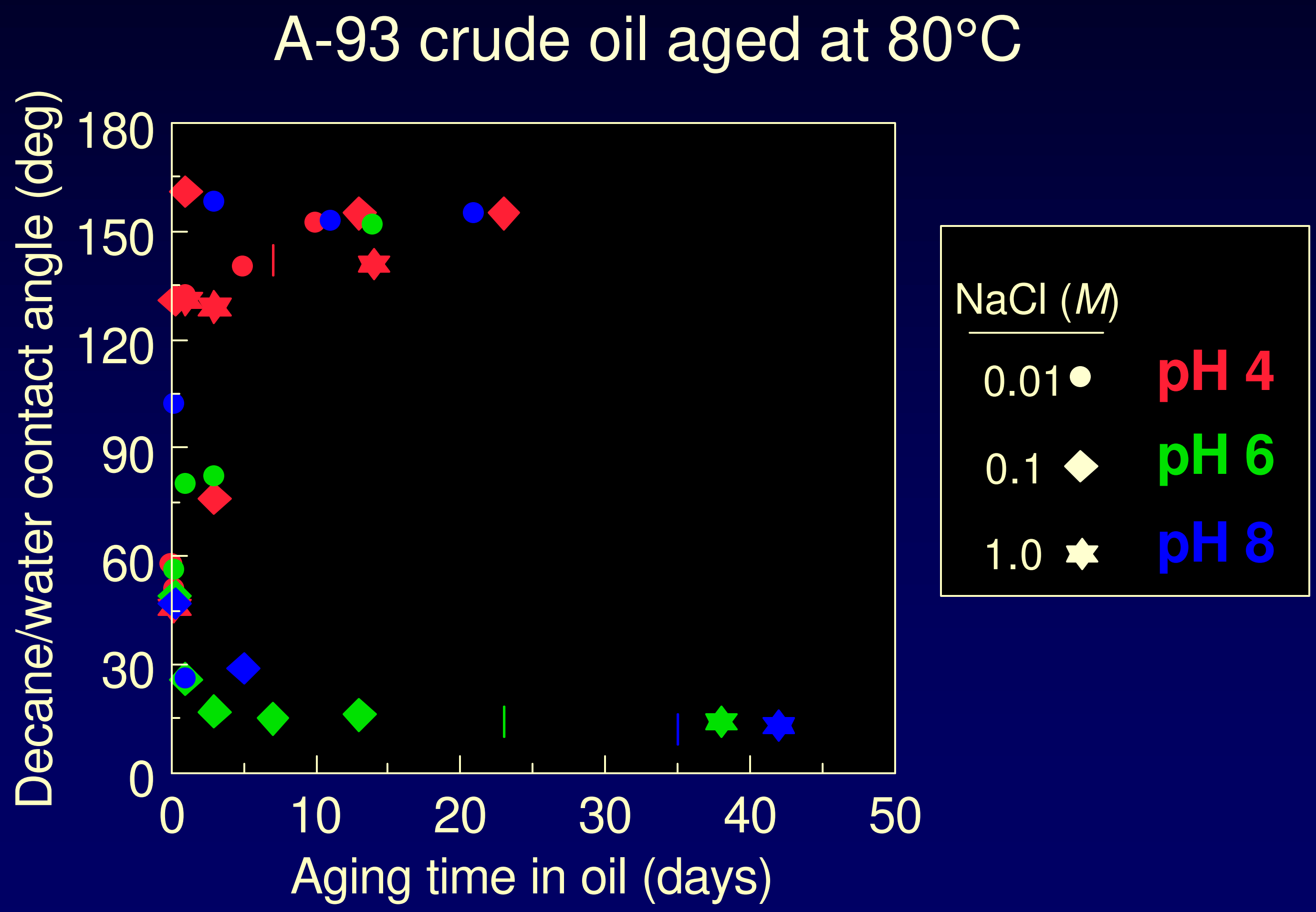
Acidic oil components

low pH ⟶ high pH





Examples of acid/base interactions



Mechanisms of interaction

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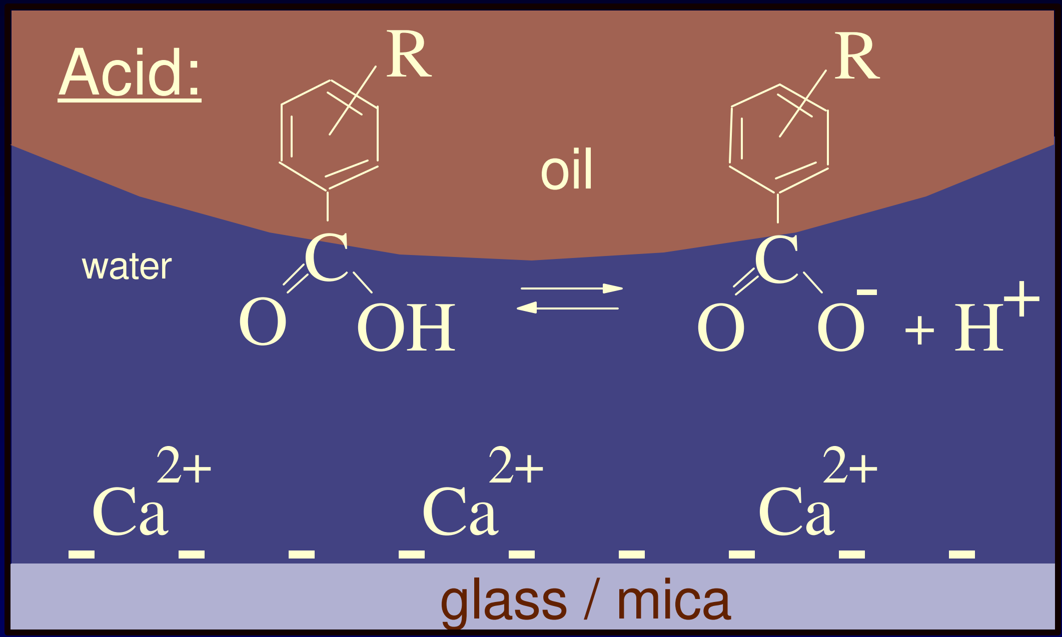
Ion binding



- slow interactions
- can be very strong
- not very predictable

Mechanisms of interaction

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- Ionic (water present)
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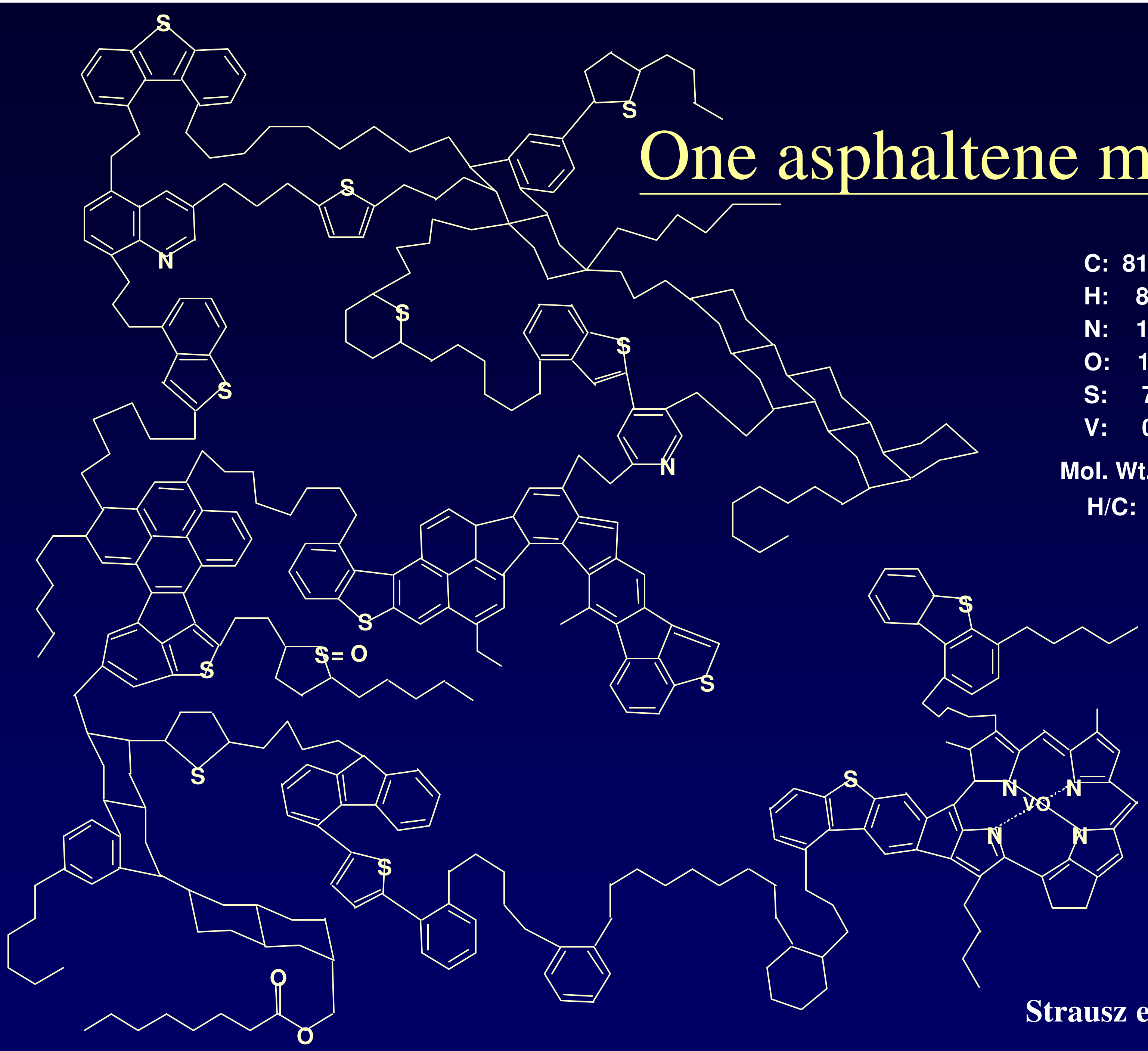
One asphaltene molecule?

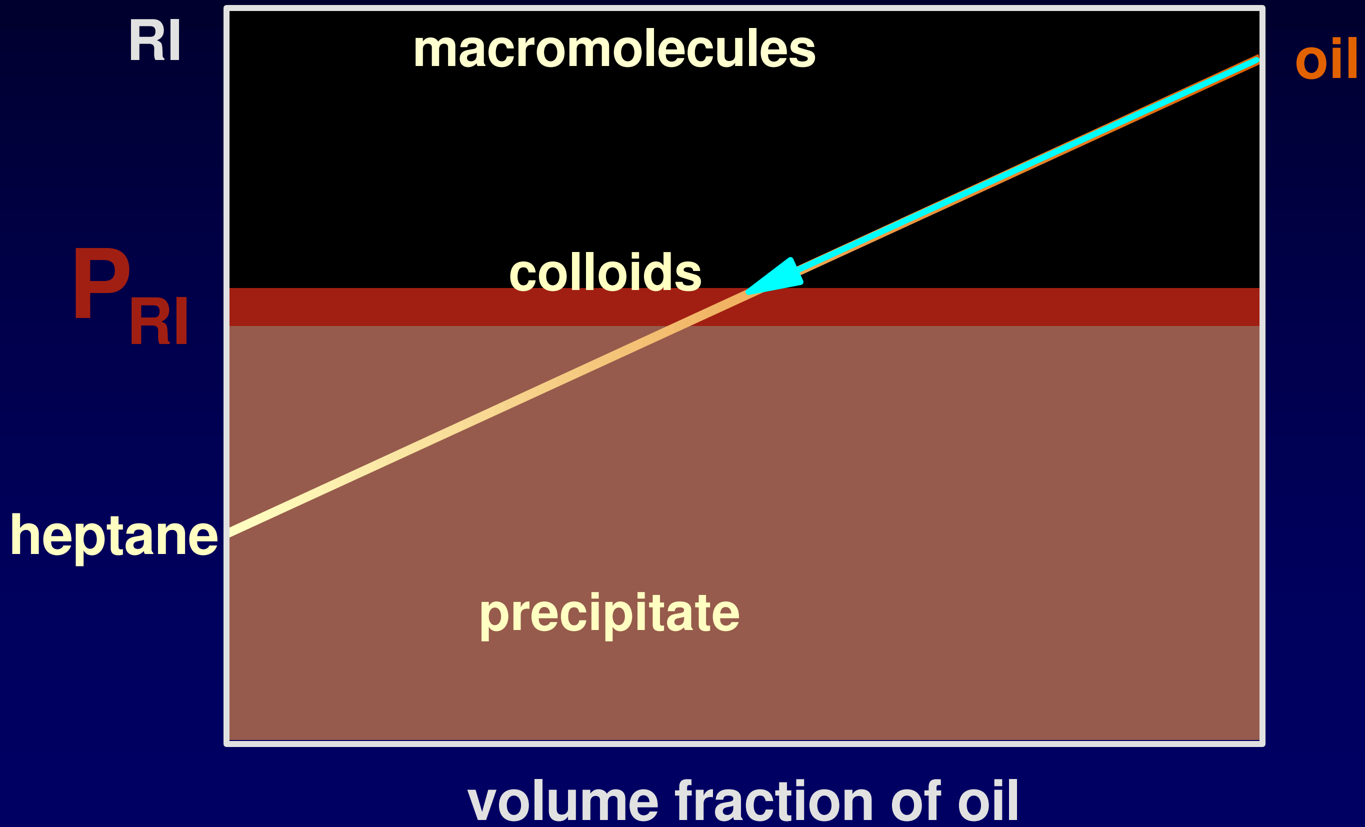


C: 81.0%
H: 8.0%
N: 1.4%
O: 1.0%
S: 7.3%
V: 0.8%

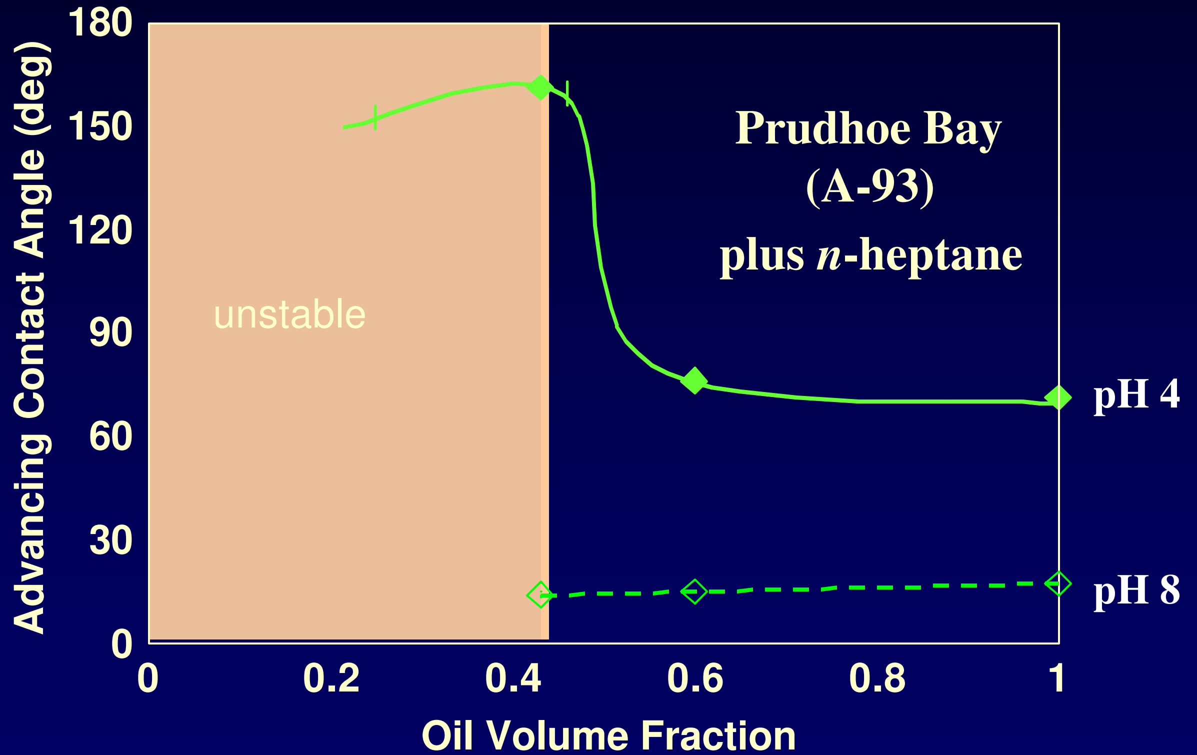
Mol. Wt.: 6191
H/C: 1.18

Strausz et al., 1991

Asphaltene aggregation

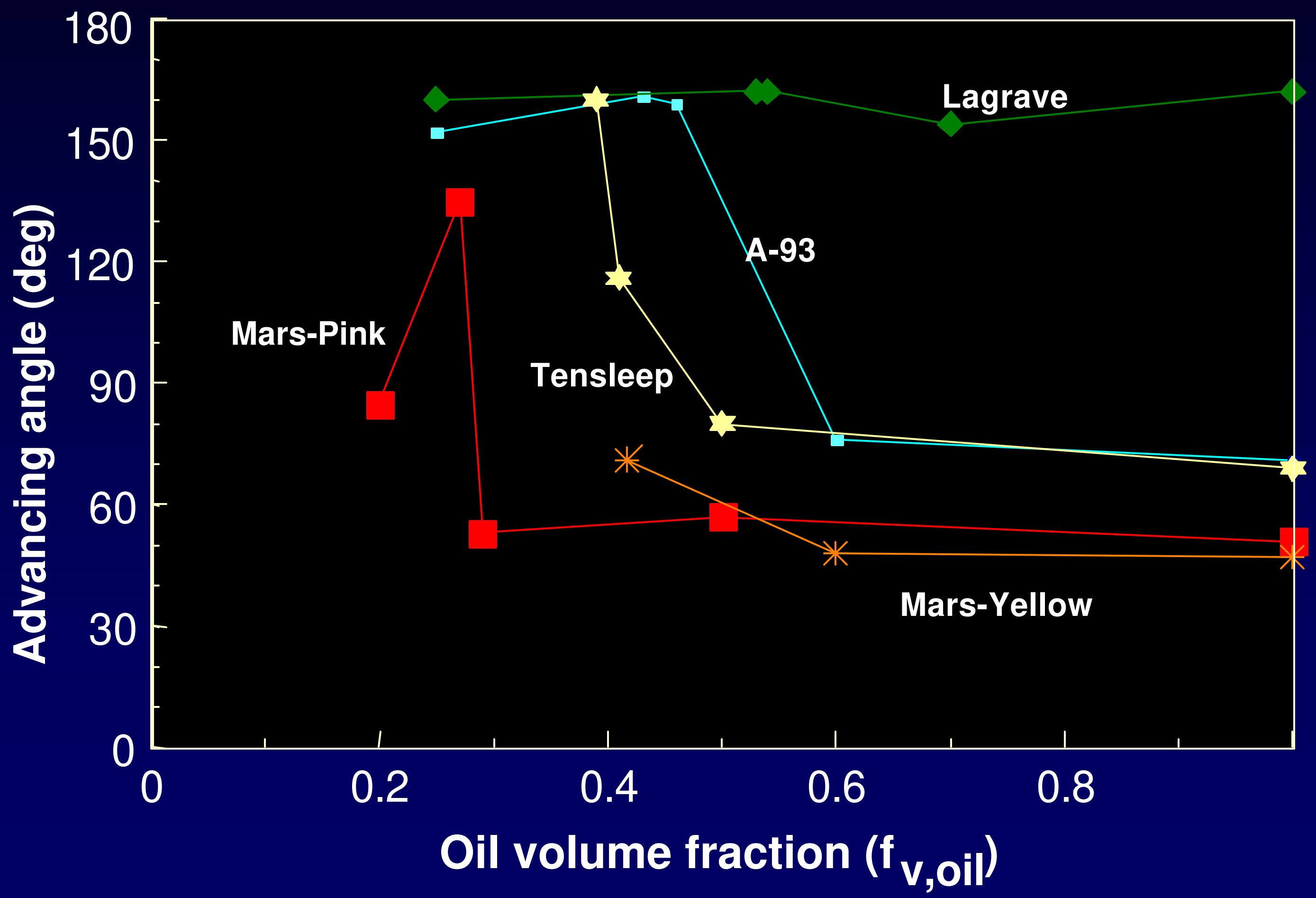


Effects of asphaltenes on wetting

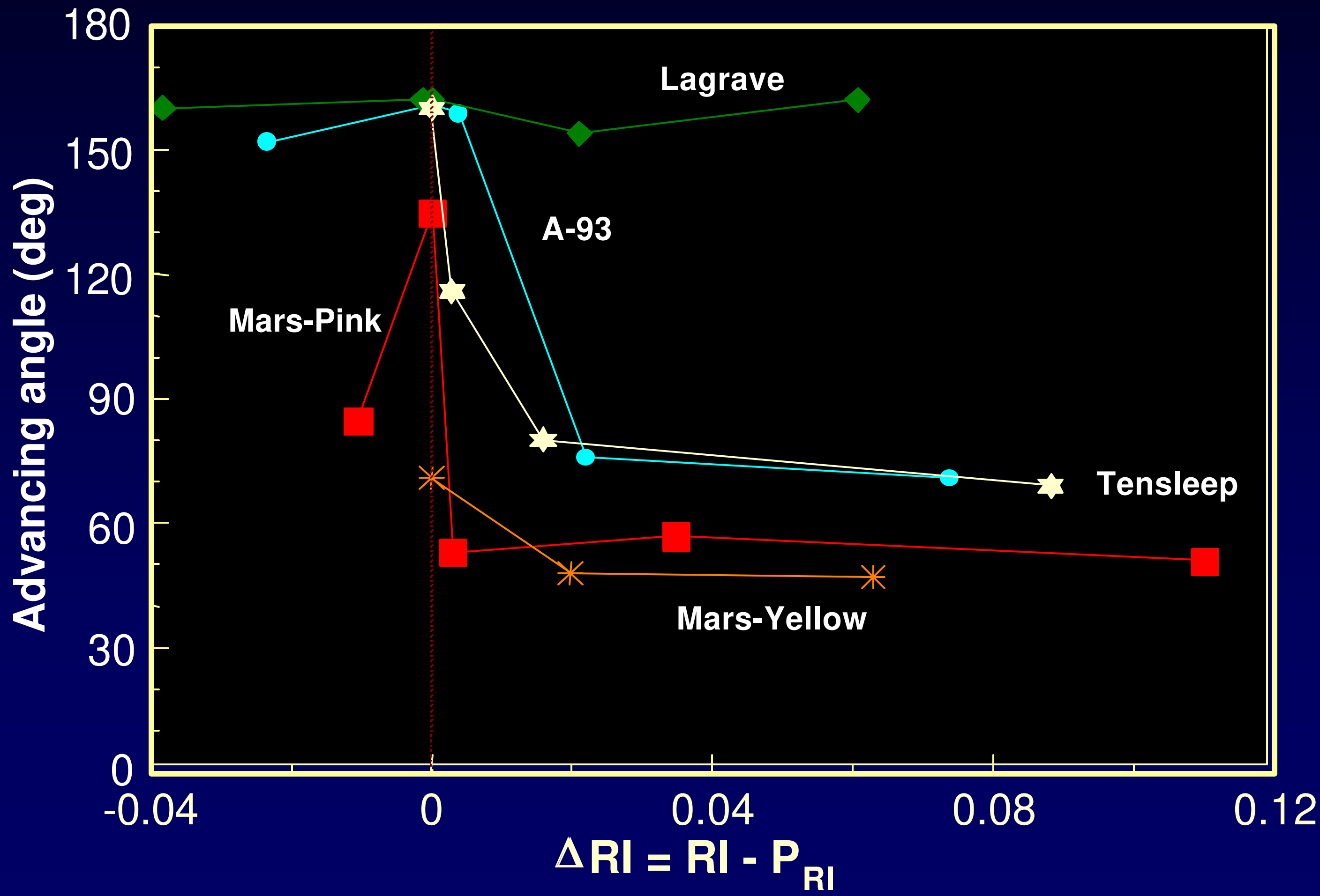


Al-Maamari and Buckley, SPE 59292

More examples



High contact angles at onset



Summary

- Oil is found in the small pore spaces in rocks where it coexists with water (and possibly a gas phase).
- Capillary forces can hold oil in place.
- Magnitude of capillary forces depends on
  - pore size
  - IFT
  - wettability (contact angles)
- Wettability is determined by surface chemistry