SCA 2018 Wettability Short Course

Classical Petrophysical Measurements of Wettability

Jules Reed, Leading Advisor – Core Testing

August 2018

Lloyd's Register

SOCIETY OF CORE ANALYSTS

Contents

Wettability Measurements

- **Cautions**
  - Non-damaged material (mechanical/physical, chemical)
    - Damage (particularly to clays) will alter Sw/Pc relationship
    - Oxidation may change wetting
    - Precipitation may change wetting
  - Correct starting point for primary imbibition
  - **Representative** material and conditions
  - Correct fluids
    - Dead or Live oil ? - (>200 scf/bbl, 40 v/v)

Wetting State

- Fresh State (Native, As Received)
  - Requirements
    - No saturation change
      - Oil-based mud (OBM), or if WBM, no invasion (verified)
      - Preservation, no oxidation
    - No wetting change, alteration of fluids or fluid composition?
      - Asphaltene precipitation?
      - Salt precipitation?
      - Process for exchanging altered fluids (without changing wettability of saturation history)
      - If OBM – no surfactants
      - Change in temperature/pressure during trip to surface

Wetting State

- Clean State
  - Test steps
    - Cleaning (must maintain mineral structure)
    - Saturate
    - Establish Swi (gas or non-polar mineral oil)
    - Wettability (from primary imbibition)
  - Why might clean state be used?
    - For 1ry drainage processes
    - For most gas reservoirs
    - To check cleaning efficiency

Wetting State

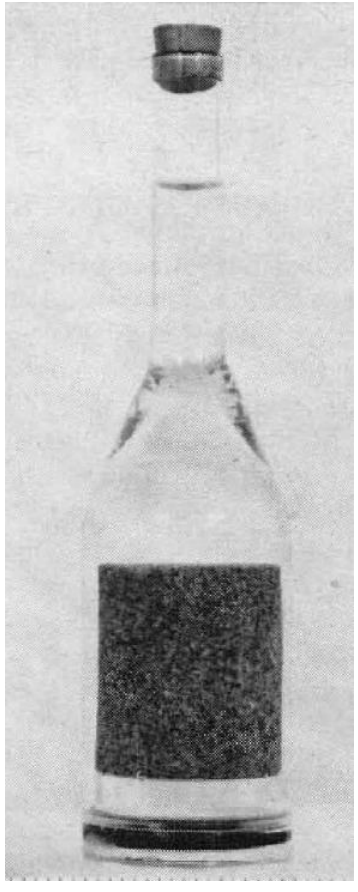
- Restored State
  - Test steps
    - Cleaning (must maintain mineral structure)
    - Saturate
    - Establish Swi (gas, no-polar mineral oil, dead oil, live oil)
    - ageing (T_{res}, P_{res}, time?, live/dead oil?)
    - wettability (from primary imbibition)
  - Wettability (from primary imbibition)

Wettability Measurements

- Quantitative
  - Amott
  - USBM
  - Capillary pressure
  - Combined Amott/USBM
  - Contact angle goniometry
- Qualitative
  - Spontaneous imbibition
  - Flotation method
  - Relative permeability
  - Log-based

Wettability - Amott

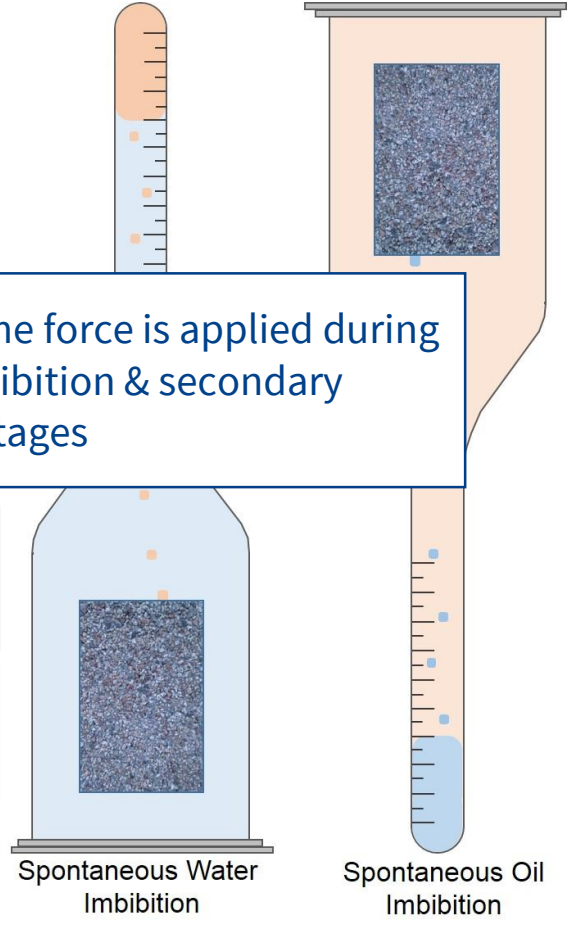
Amott, 1958



- Spontaneous Imbibition (si)
  - Volume displaced = volume imbibed
  - Oil or water
- Forced Imbibition (fi)
  - Centrifuge (Amott)
  - Flooding (Amott-Harvey)

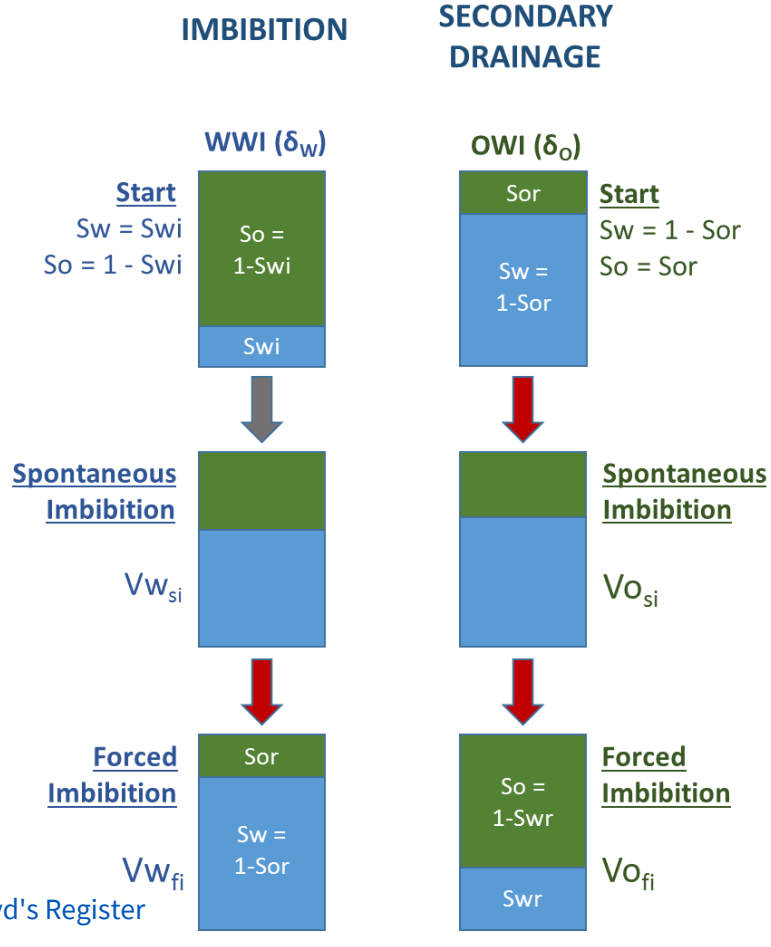
NB. Ensure same force is applied during forced imbibition & secondary drainage stages

Primary Imbibition (Sw increasing)	Secondary Drainage (Sw decreasing)
Water Wet Index (WWI)	Oil Wet Index (OWI)
$\delta_w = \frac{V_{w_{si}}}{V_{w_{si}} + V_{w_{fi}}}$	$\delta_o = \frac{V_{o_{si}}}{V_{o_{si}} + V_{o_{fi}}}$



Wettability - Amott

Amott-Harvey



Water Wet Index (WWI)

$$\delta_w = \frac{V_{w_{si}}}{V_{w_{si}} + V_{w_{fi}}}$$

Oil Wet Index (OWI)

$$\delta_o = \frac{V_{o_{si}}}{V_{o_{si}} + V_{o_{fi}}}$$

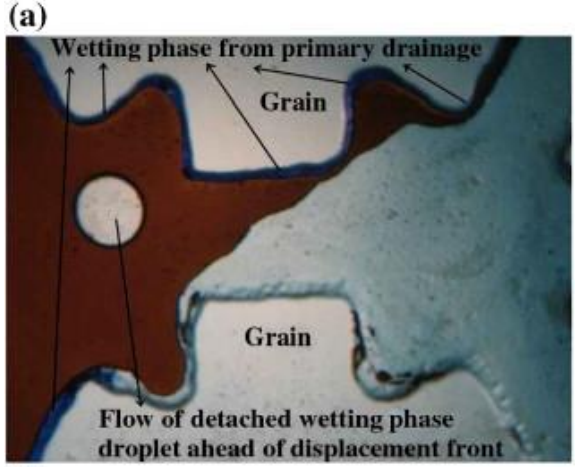
The larger the individual phase wetting index, the greater the wetting preference to that phase

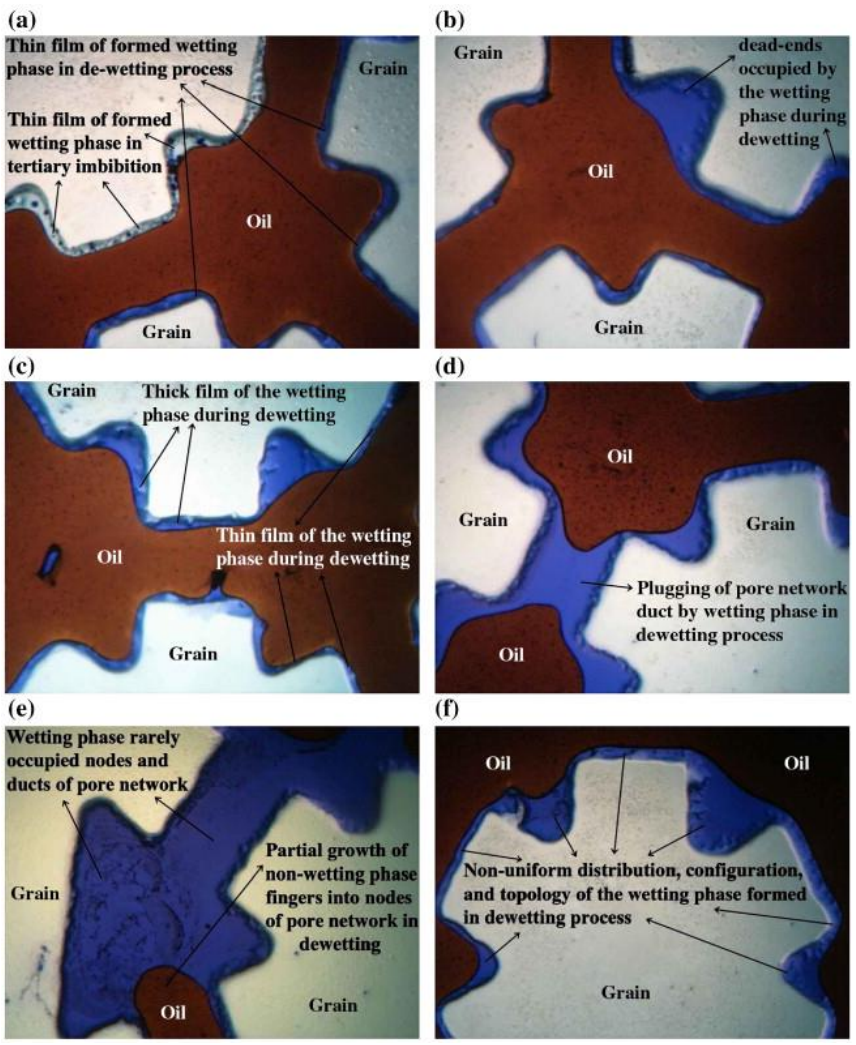
Amott-Harvey Wetting Index (AHWI) = δ_w - δ_o

Index	Oil Wet	Neutral Wet	Water Wet
δ_w	$+_{ve}$	0	0
δ_o	0	0	$+_{ve}$
AHWI	-1.0 to -0.3	-0.3 to +0.3	+0.3 to +1.0

Wettability - Amott

Spontaneous Imbibition - Strong wetting-phase

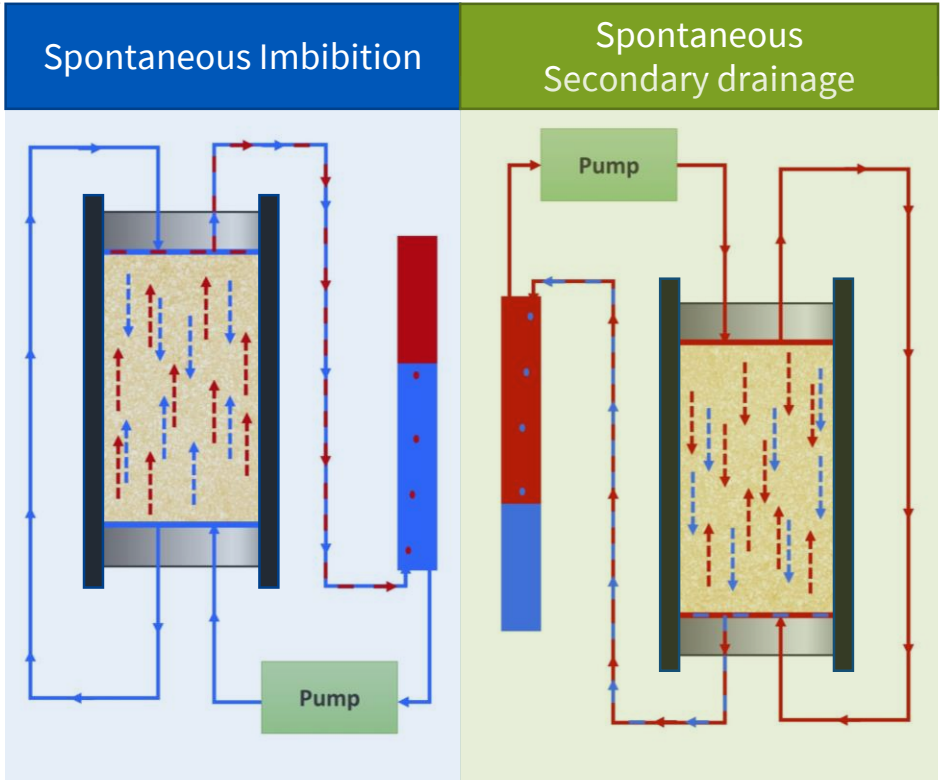




Jamaloei, etal. JPSE June 2010, pp251-269

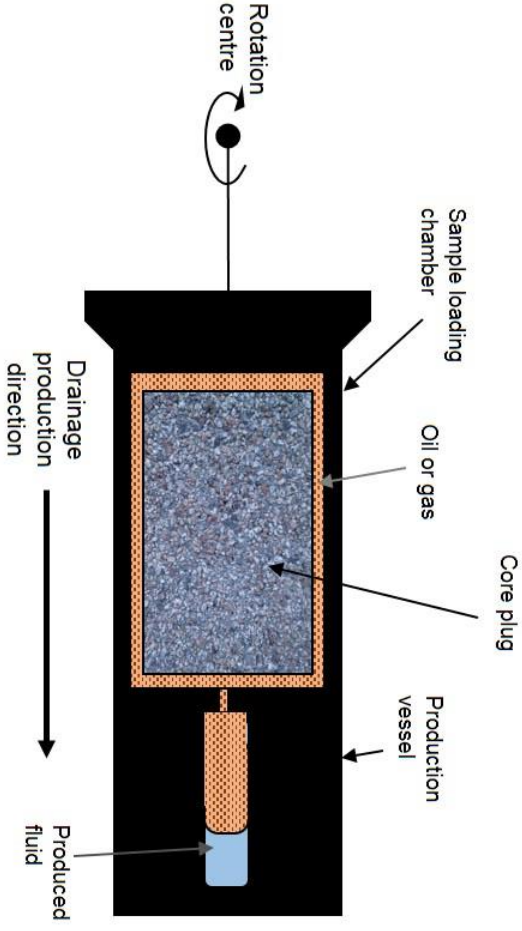
Wettability – Amott – Reservoir confining stress

- Spontaneous stages in a coreholder
- Forced stages
  - Coreflooding
  - overburden centrifuge
    - (may require transfer between coreholders)
- Good for unconsolidated core
  - Whole experiment in same coreholder



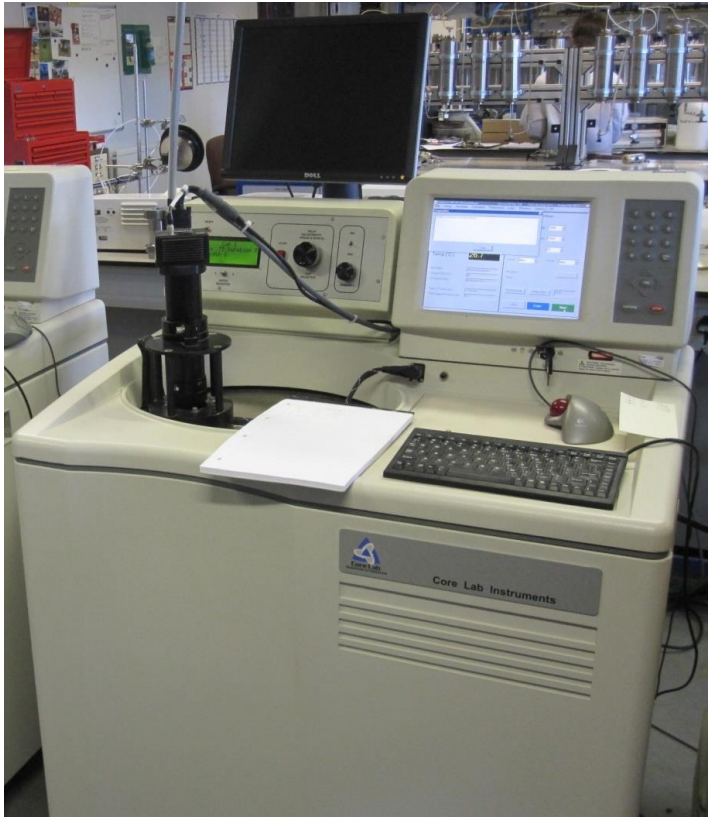
Wettability - USBM

- USBM
  - No spontaneous stage of testing
  - Forced imbibition & forced secondary drainage – centrifuge
    - Limited pressure applied in true USBM (10 psi)
    - Determine ratio of area under the described curves



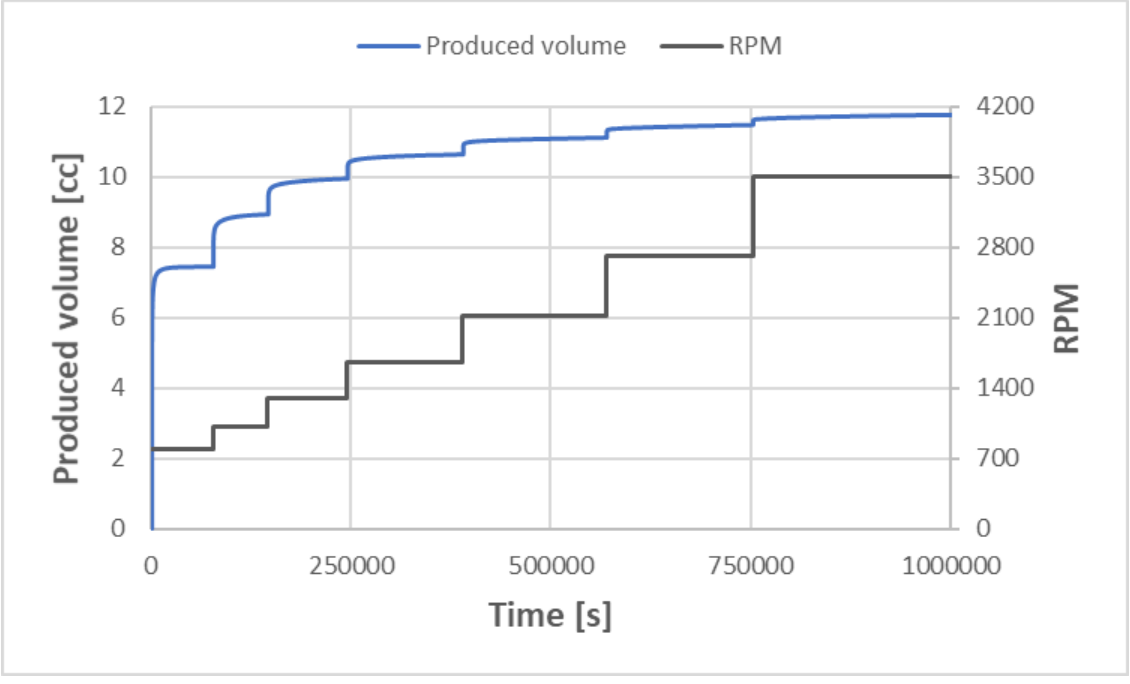
Wettability - USBM

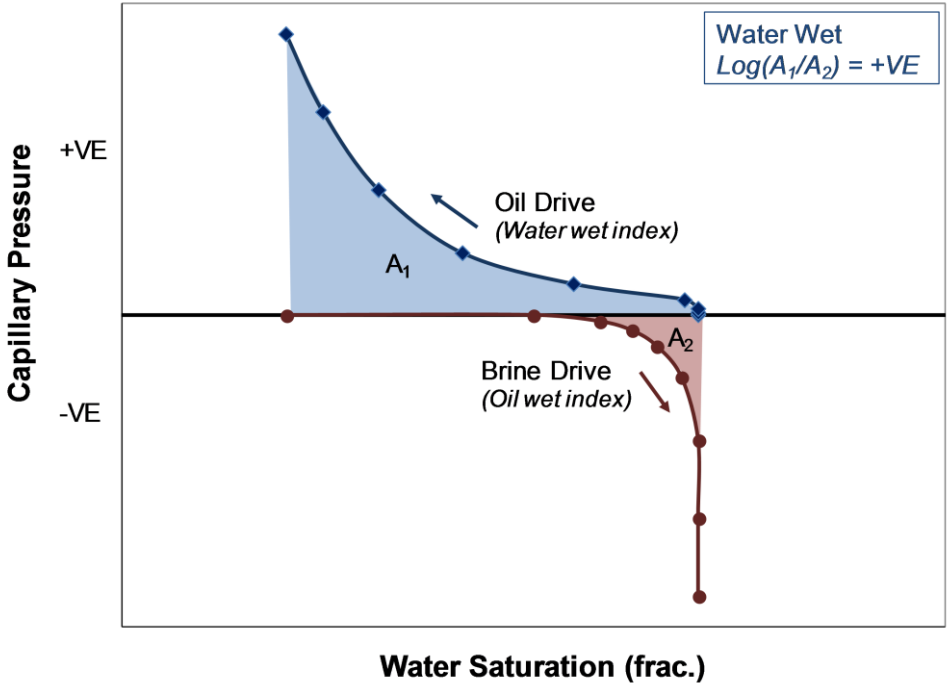
- USBM



Wettability - USBM

- USBM





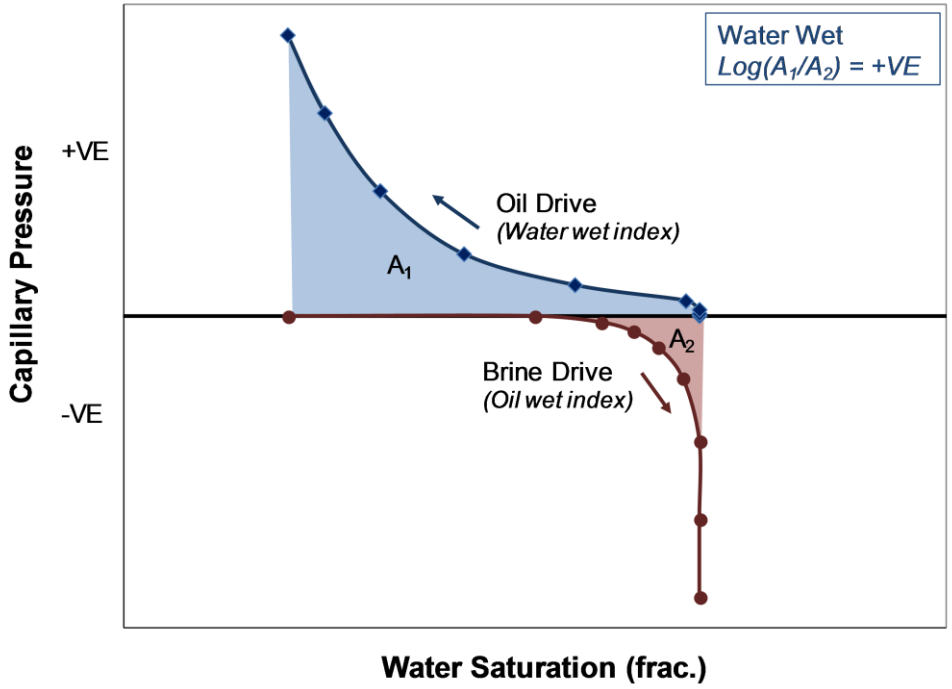
$$USBM = \log\left(\frac{A_1}{A_2}\right)$$

A2 > A1 Oil Wet
A2 < A1 Water Wet
A2 ≈ A1 Neutral Wet

Wettability - USBM

- USBM Tests

	Water Wet	Neutral Wet	Oil Wet
USBM	Positive	0	Negative



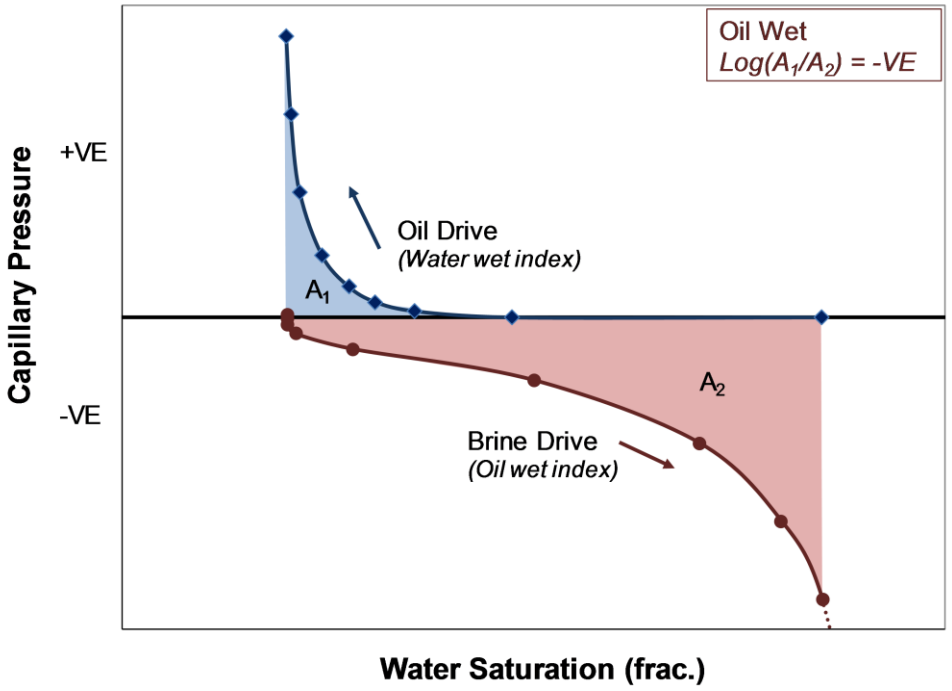
$$USBM = \log\left(\frac{A_1}{A_2}\right)$$

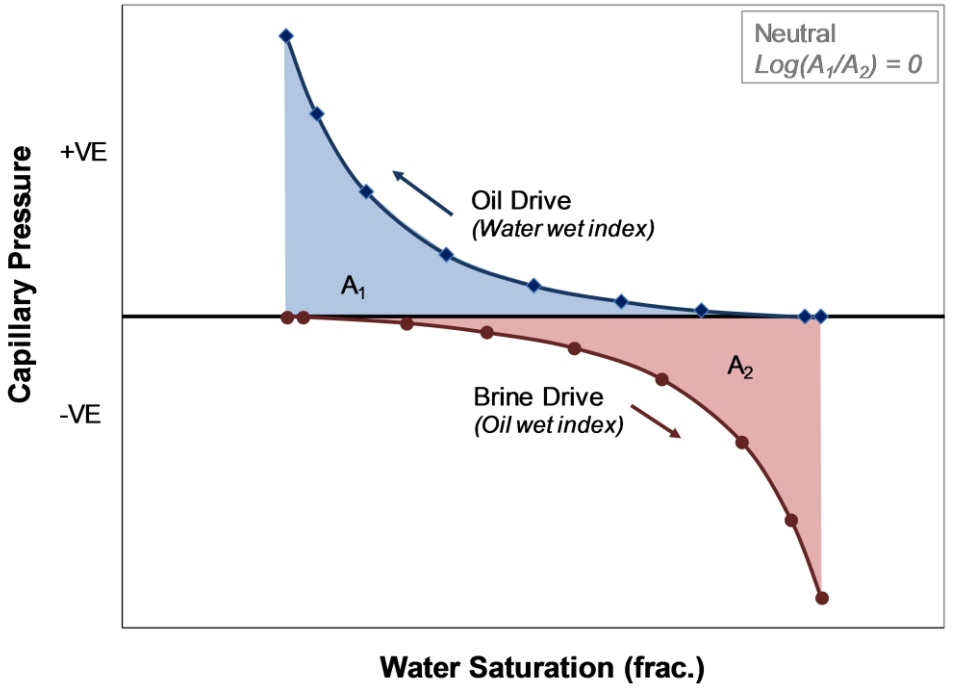
A2 > A1 Oil Wet
A2 < A1 Water Wet
A2 ≈ A1 Neutral Wet

The larger the absolute value of A,
the greater the wetting preference to that phase

Wettability - USBM

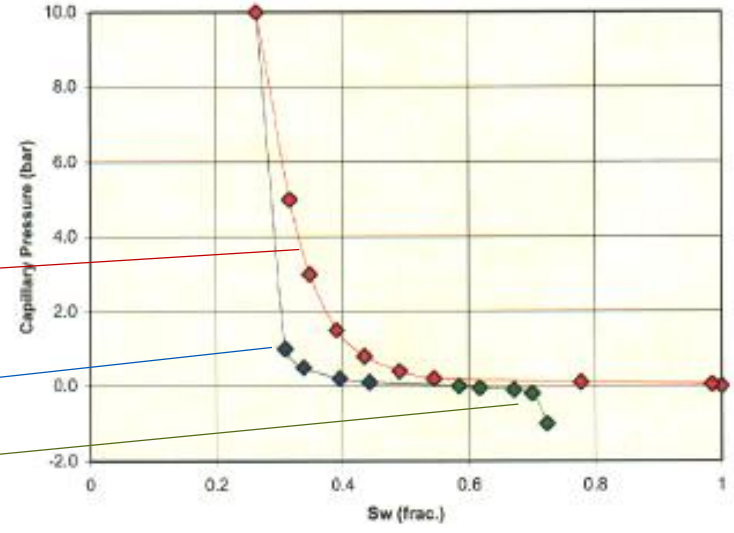
	Water Wet	Neutral Wet	Oil Wet
USBM	Positive	0	Negative

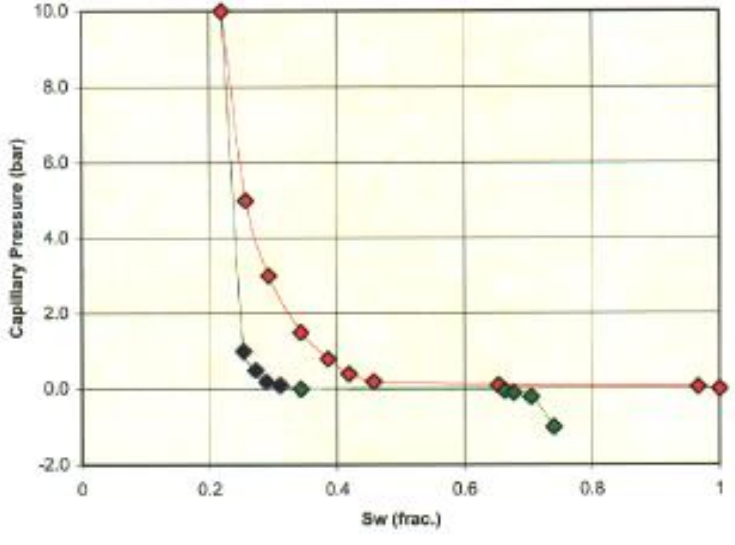




Wettability – Capillary pressure

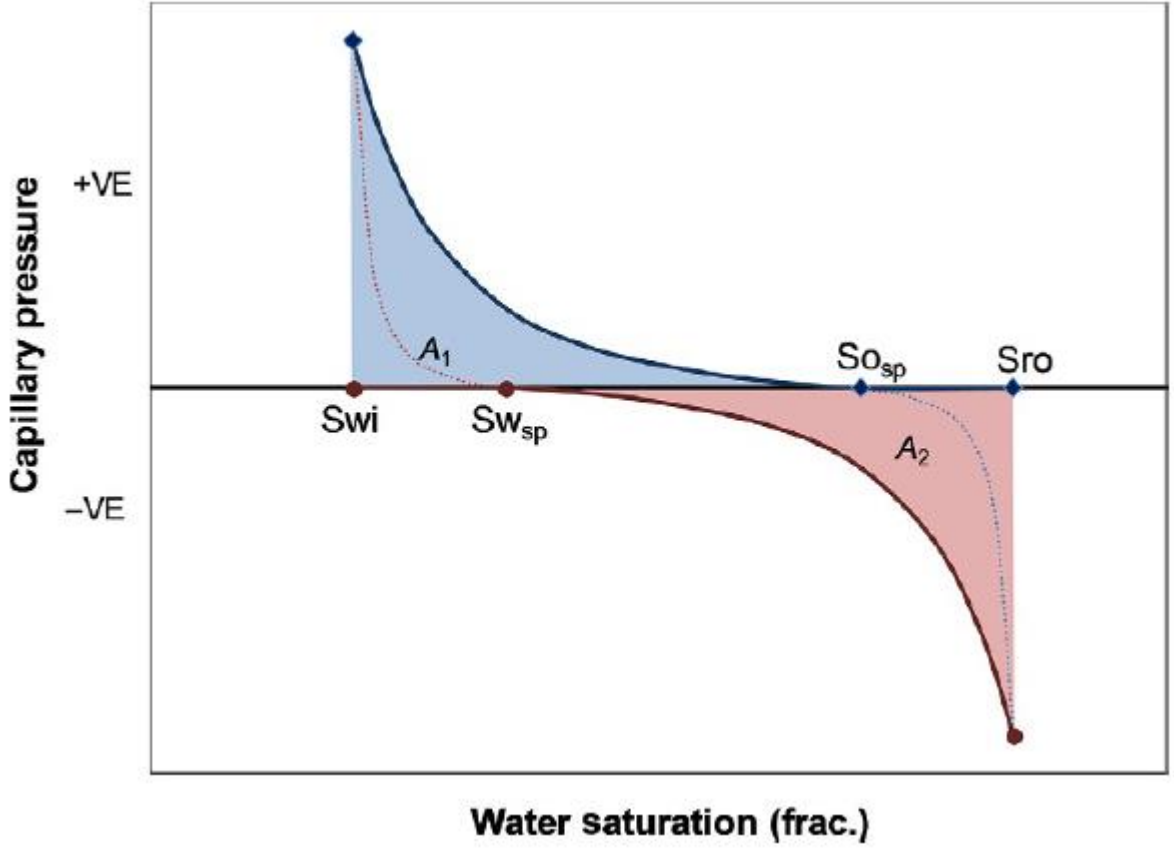
- Capillary pressure by the porous plate method can provide full curves in:
  - Primary drainage
  - Primary Imbibition
    - Spontaneous
    - Forced
  - Secondary drainage
    - Spontaneous
    - Forced
  - Few have capability for all three stages
  - Very long test times (1.5 – 2 yrs)





Wettability – Combined Amott/USBM

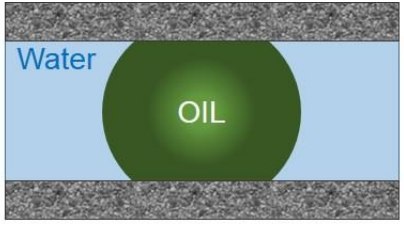
- As the name suggests
  - Spontaneous = Amott
  - Forced = USBM
    - Often using Pc > 10 psi

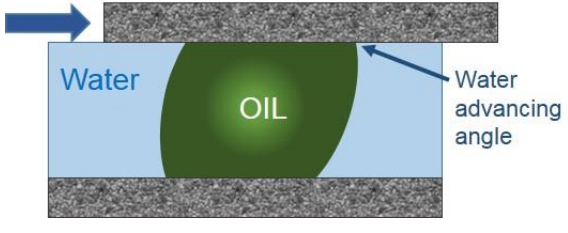


NB. Applied force should still be equivalent in imbibition and drainage

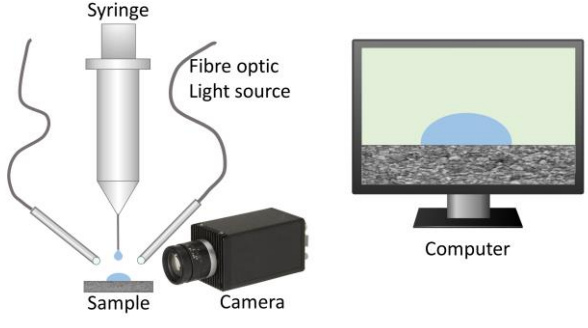
Contact Angle Goniometry

- Sessile drop technique
  - Goniometer
  - measure contact angle visually
- Modified sessile drop





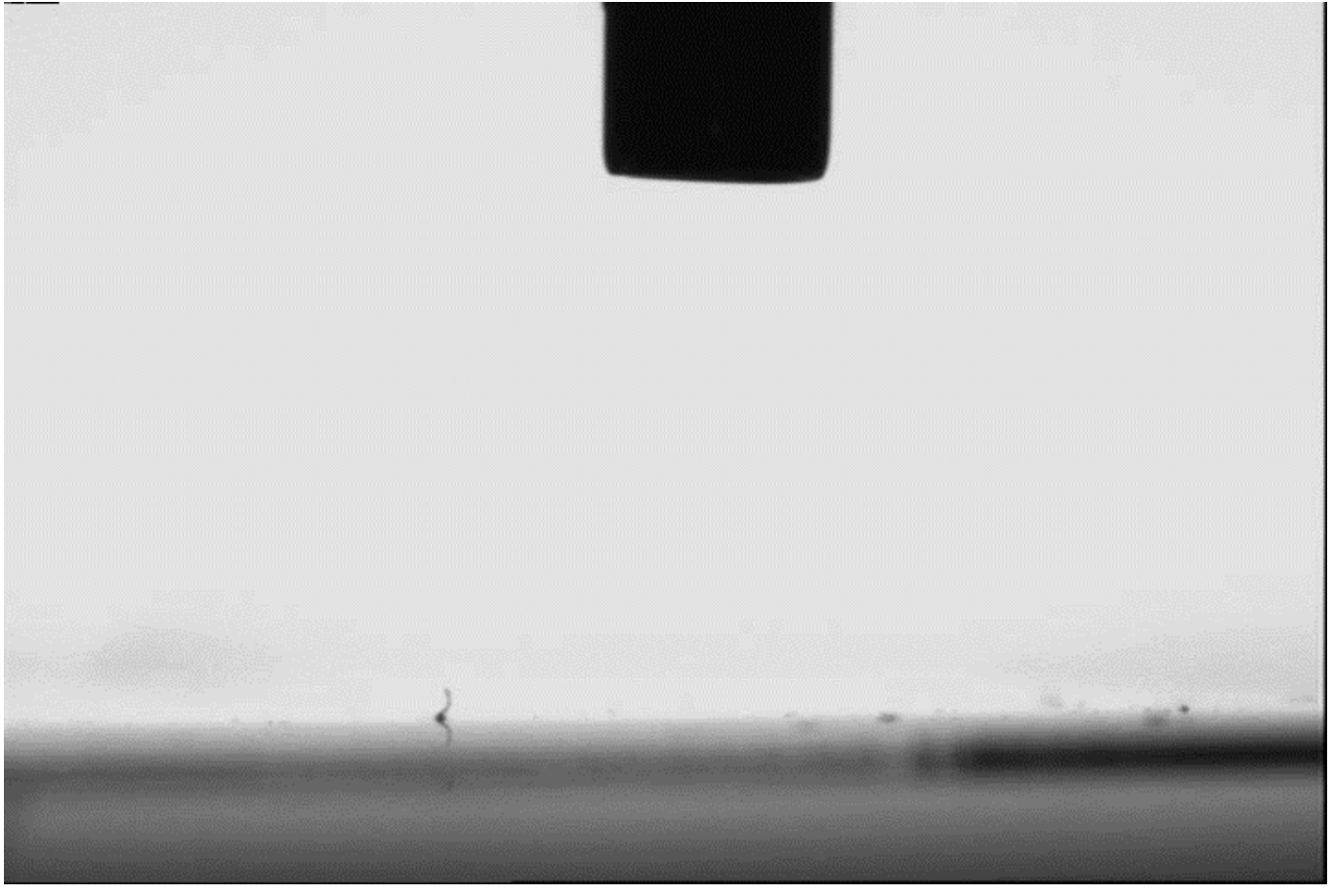
Advancing – imbibition
Receding – drainage
Advancing > imbibition



Contact Angle Goniometry

Wetting

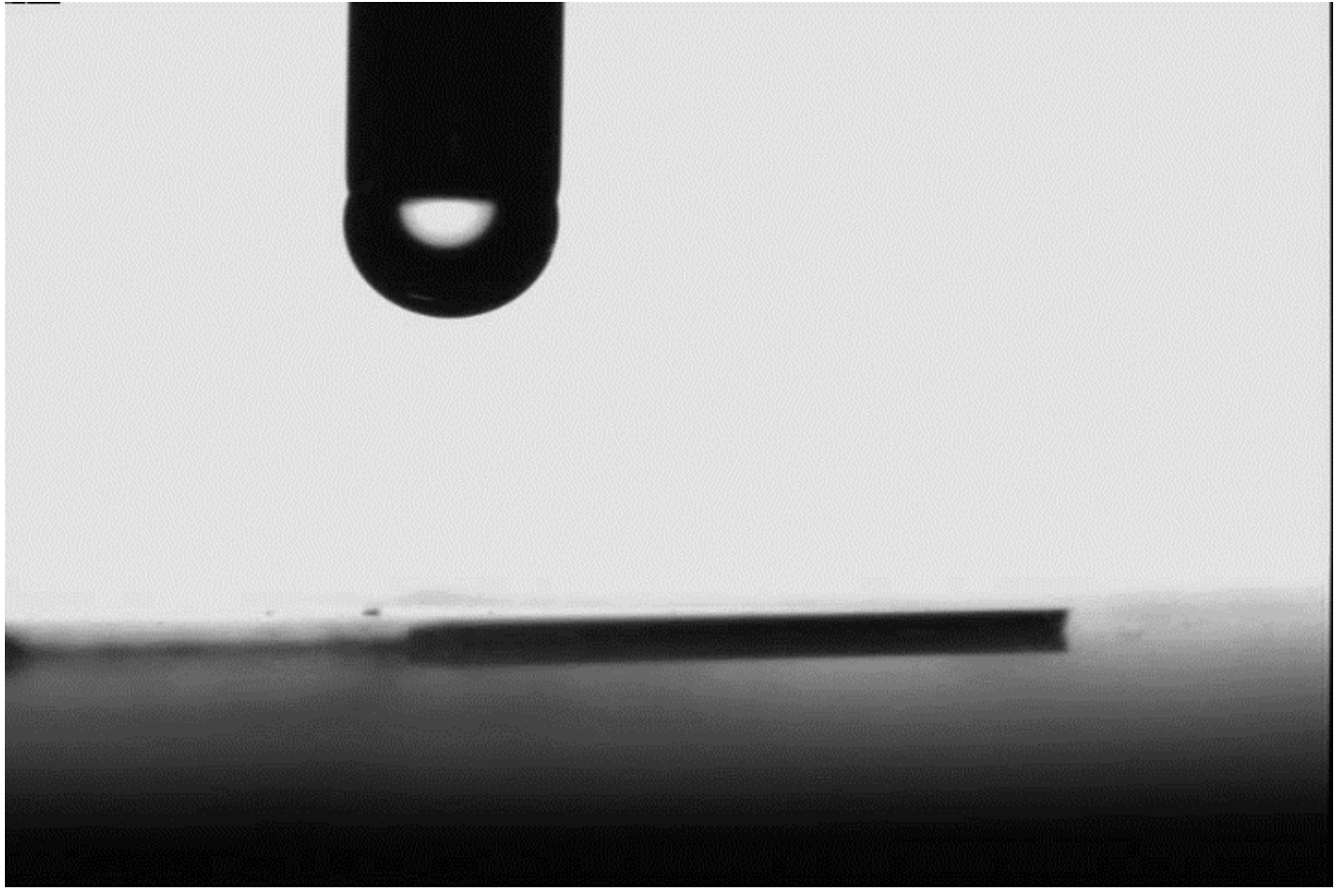
Courtesy: Dr. J. Bird, Boston University



Contact Angle Goniometry

Mixed Wet

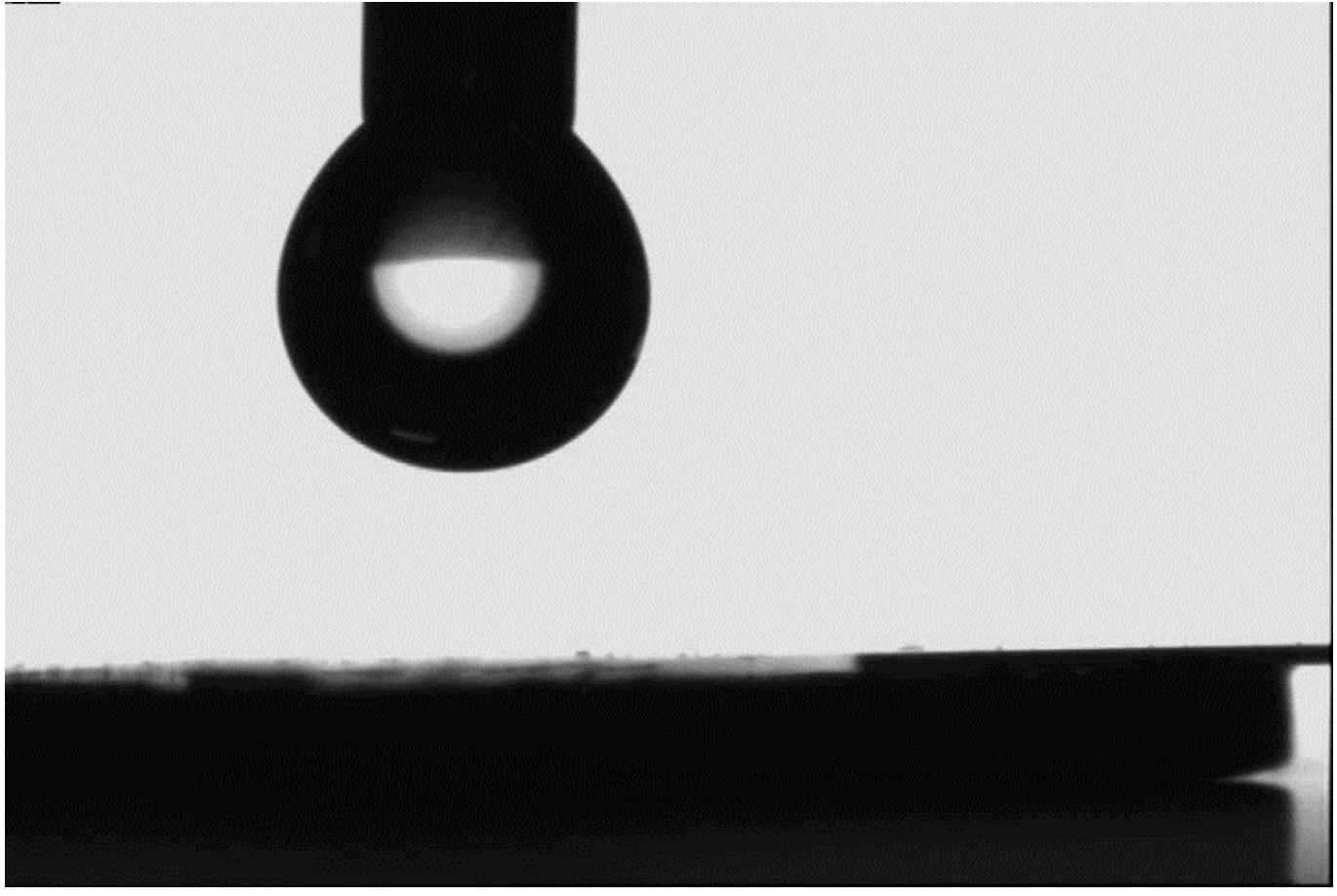
Courtesy: Dr. J. Bird, Boston University



Contact Angle Goniometry

Non-Wetting

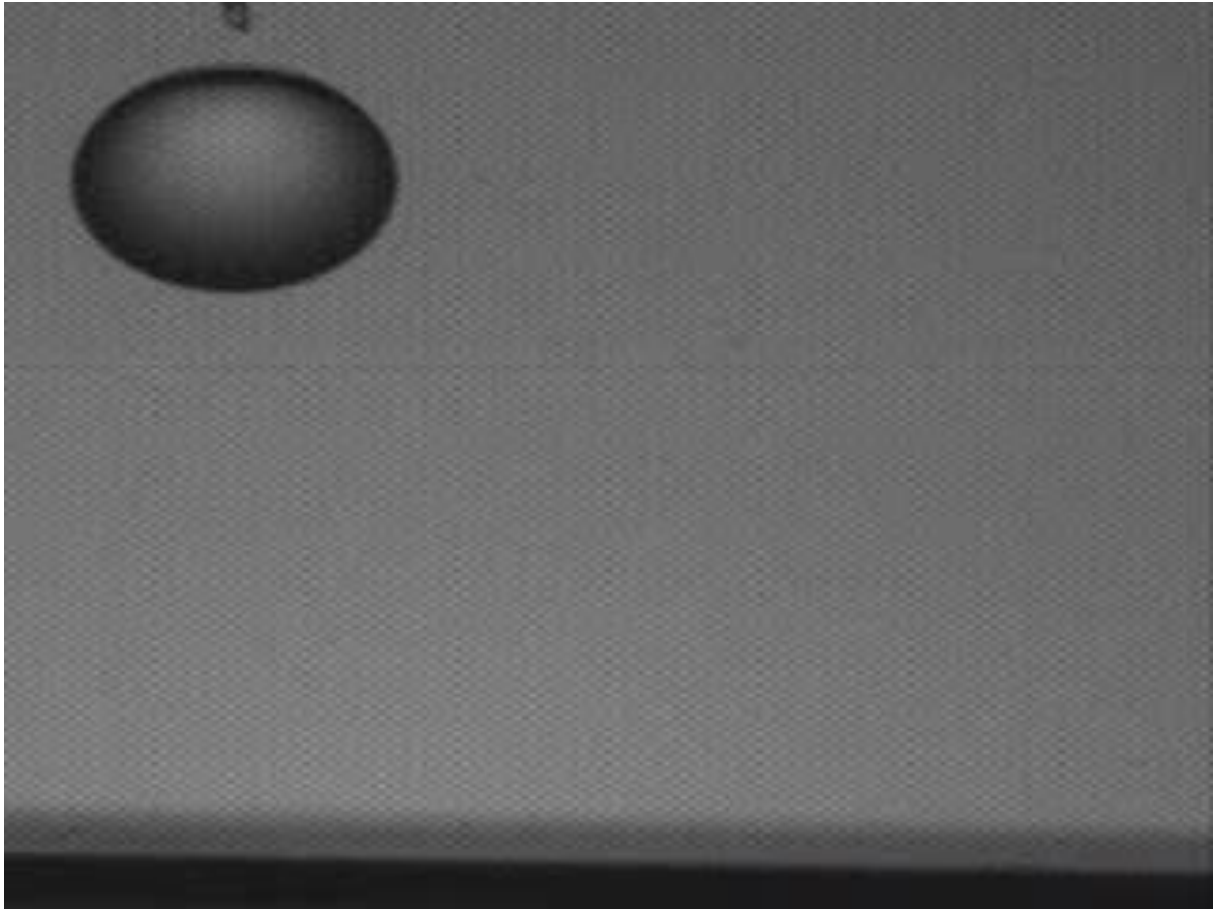
Courtesy: Dr. J. Bird, Boston University



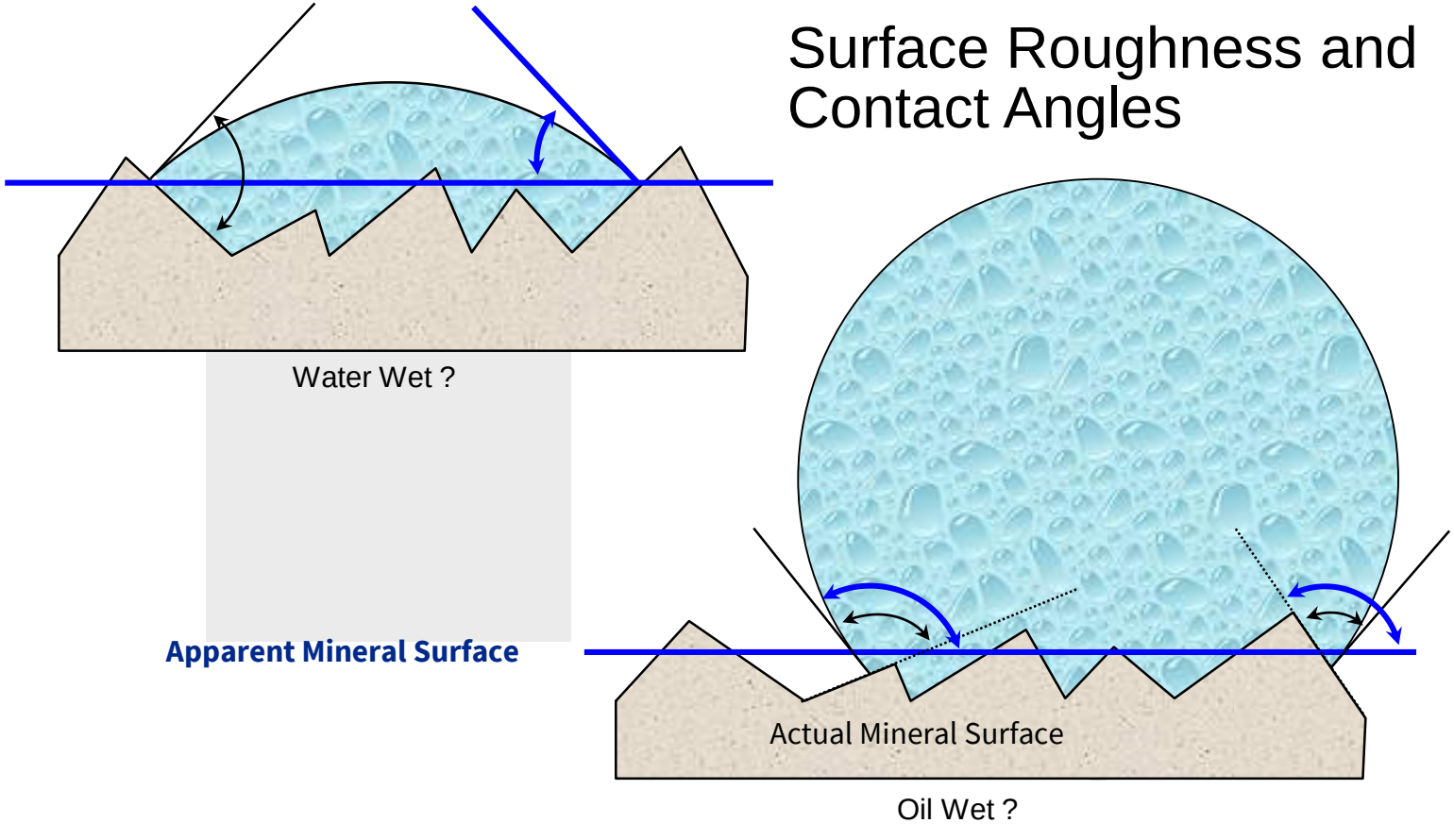
Contact Angle Goniometry

Non-Wetting

Courtesy: Dr. J. Bird, Boston University



Contact Angle – Suface roughness

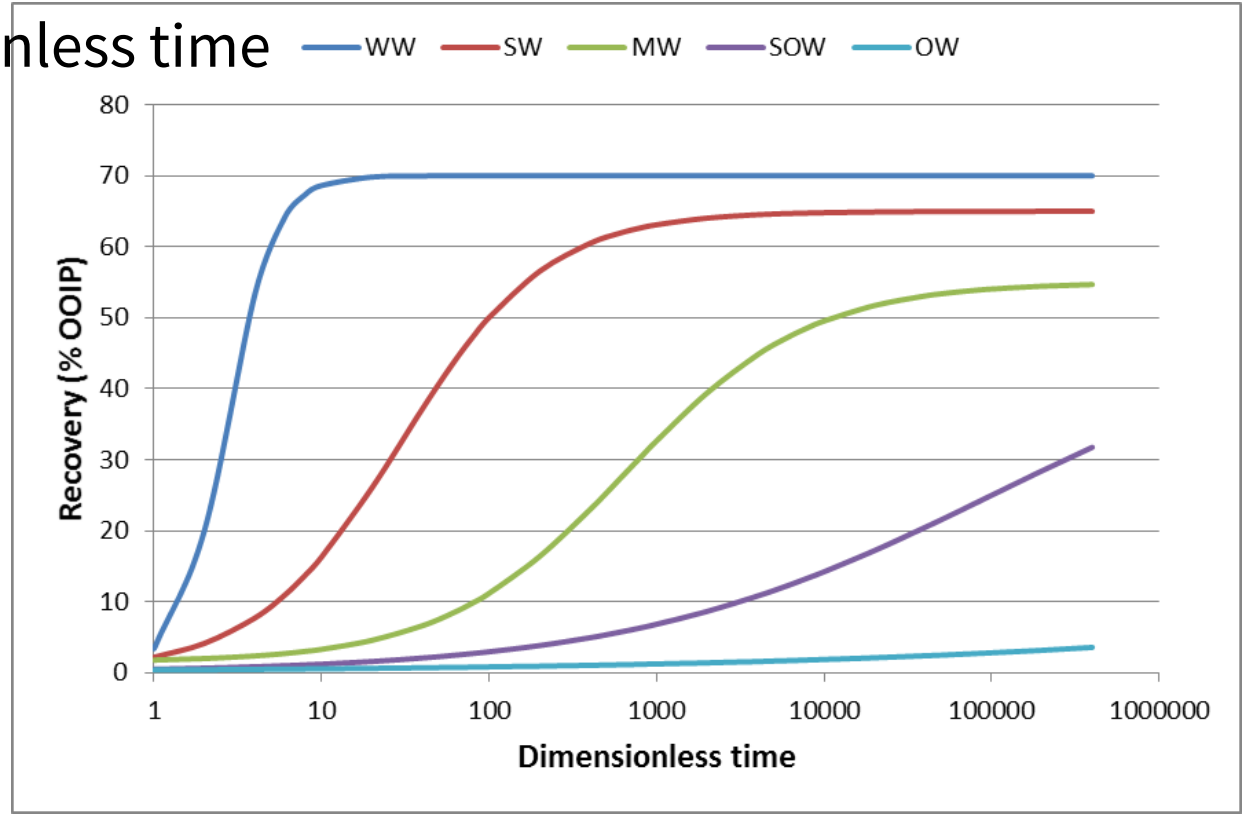


Anderson (1987) - contact angle of 50° on flat surface translates to apparent angle of 0° on rough surface

Qualitative Methods

- Spontaneous imbibition
  - Plotted against dimensionless time
    - Zhang et al. (1996)

$$t_D = t\sqrt{\frac{k}{\phi}\frac{\sigma}{\mu_s}\frac{1}{L_c^2}}$$

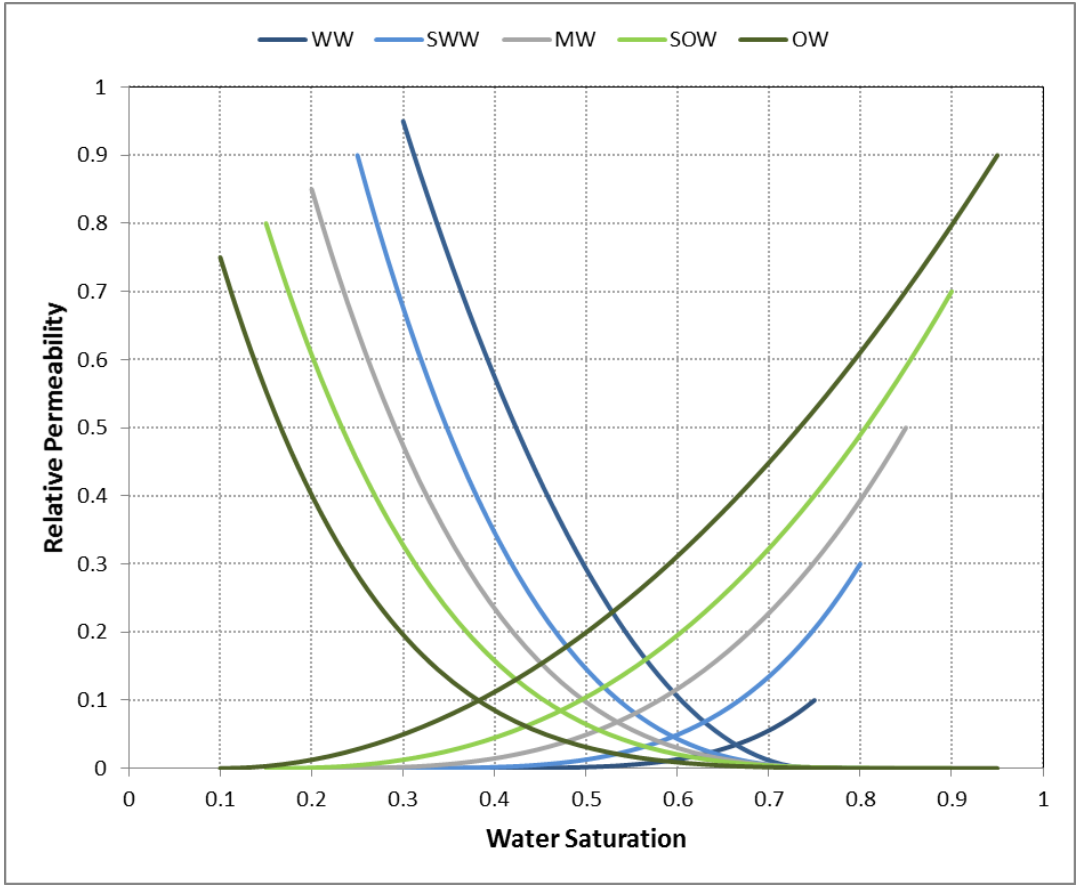


Qualitative Methods

- Flotation Method
  - Place water and oil in a test tube together with mineral substrate
  - Shake
  - Wetting is whichever fluid the mineral locates to
    - Neutral if at the interface

Qualitative Methods

- Relative Permeability
  - Craig's Rule of Thumb
    - Residual saturations
      - High Sw = WW, low Sw = OW
    - Intersect Sw
      - >0.5 WW , <0.5 = OW
    - Endpoint krw
      - < 0.2 = WW, 0.3 – 0.4 MW, >0.5 OW

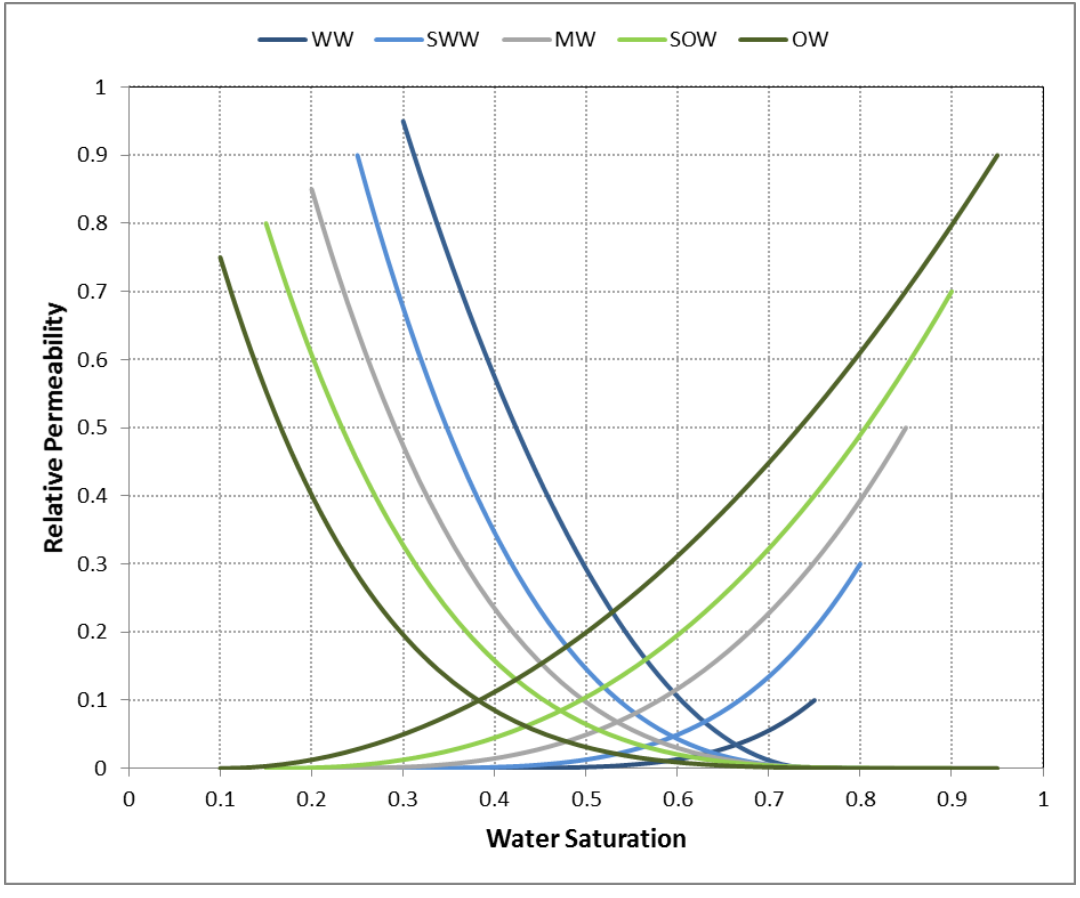


Qualitative Methods

- Relative Permeability
  - Corey Parameters

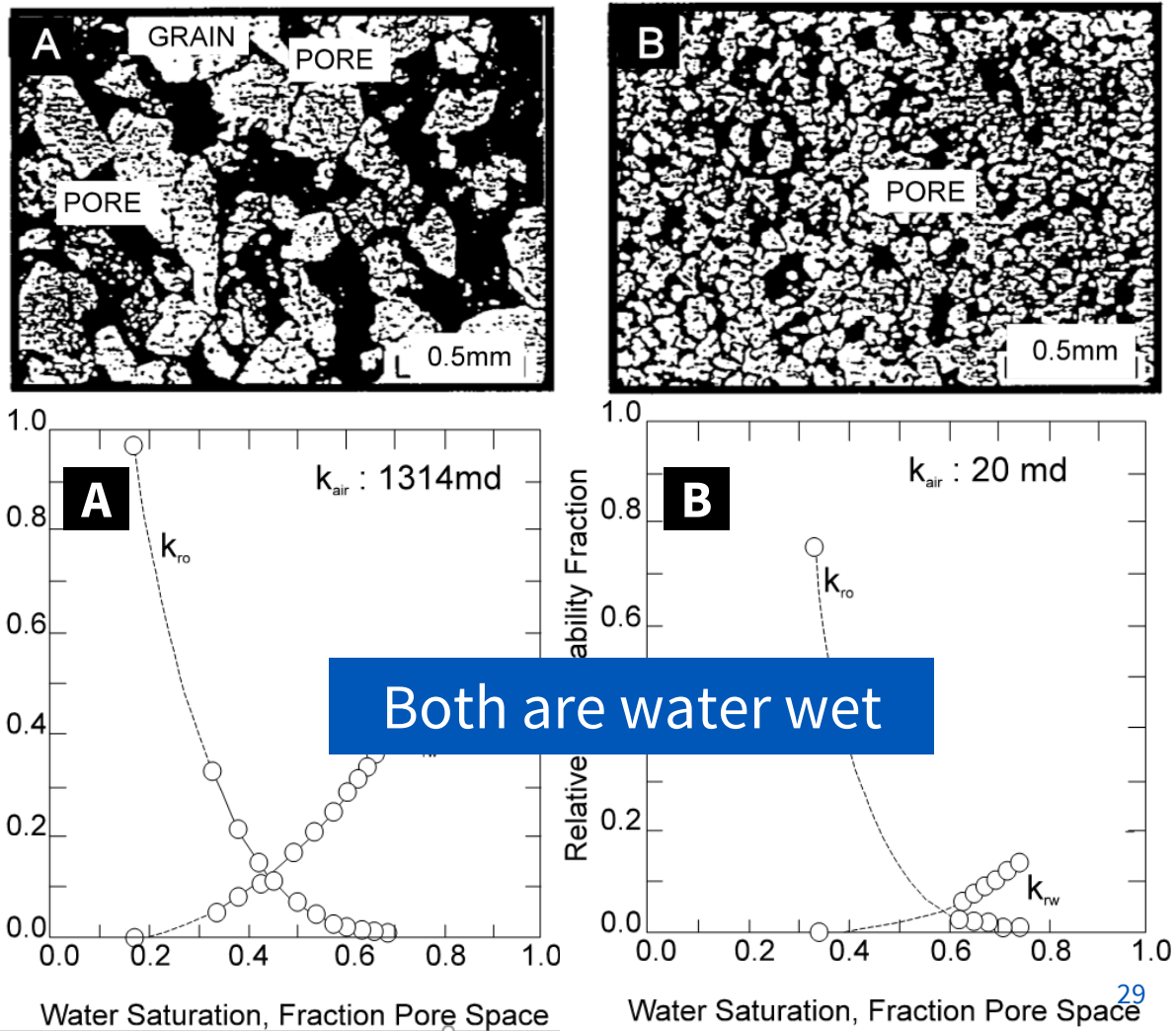
Wetting	Nw	No
Water Wet	5 – 8	2 – 4
Mixed Wet	3 – 5	3 – 5
Oil Wet	2 – 3	5 – 8

Rough guide



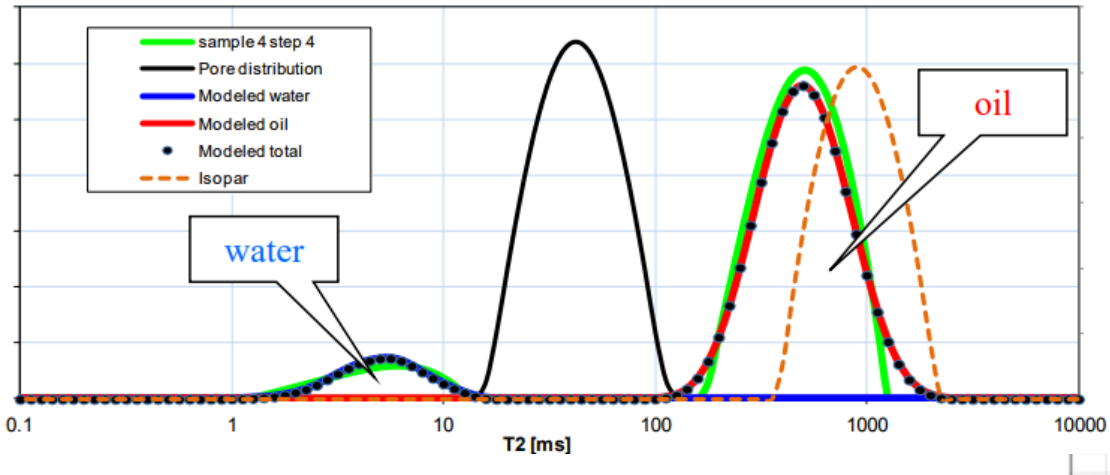
Qualitative Methods

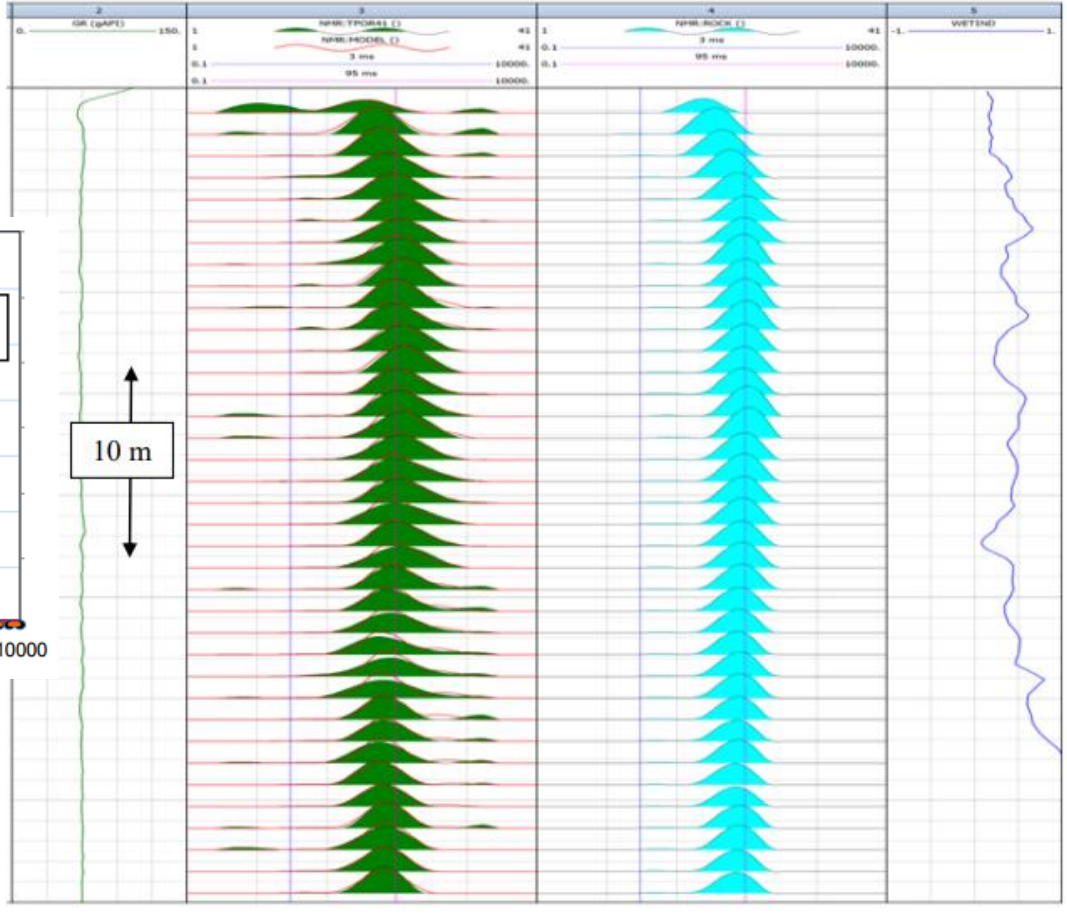
- Relative Permeability
- Beware generalisations !



Qualitative Methods

- Log-based method
  - NMR





Looyestijn, et al. (2017)

Thank you

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