Core Wettability – Can we get it right?

AFES 2020 Virtual Seminar: "*Core: the most valuable asset in your reservoir*"

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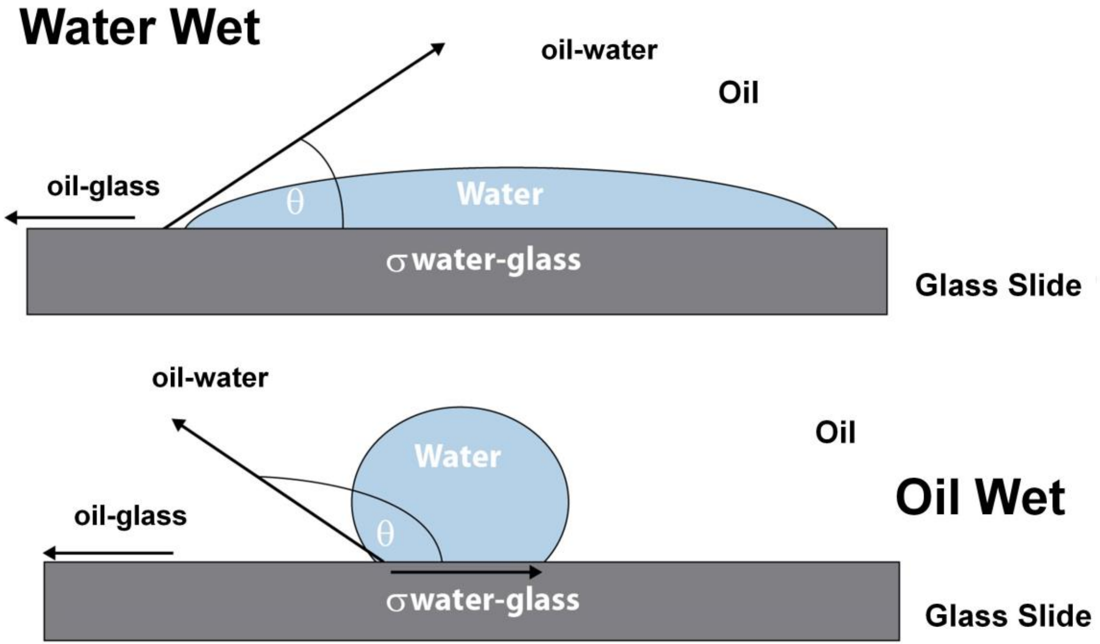
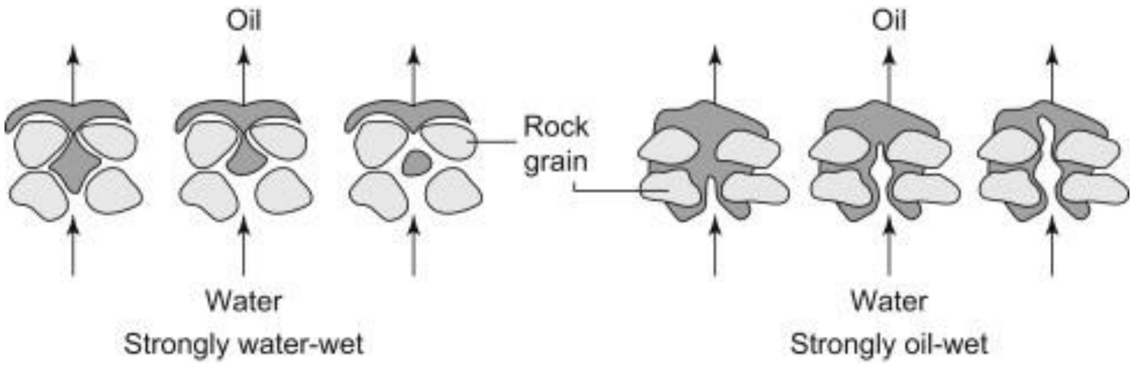
AFES Aberdeen Formation Evaluation Society

Wettability Concept



Core Analysis: A Best Practice Guide. Elsevier, 2015

Effect of Wettability in Porous Media Fluids Distribution



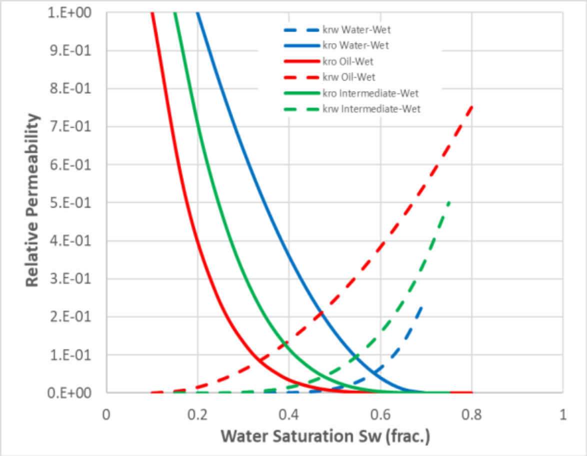
Strongly Water-Wet

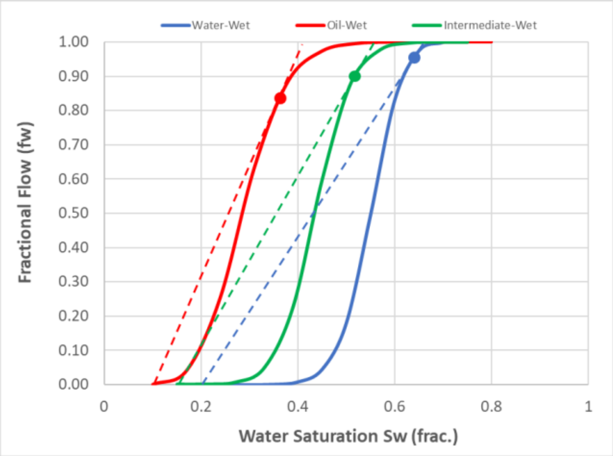
Strongly Oil-Wet

Cosentino, 2001

Importance of Wettability

- Wetting index only provides qualitative indication of reservoir properties
- Wrong wettability → Wrong reservoir performance prediction → Wrong hydrocarbon recovery





WATER WET:

Ultimate recovery = 0.63
Sor (@ fw = 0.95) = 0.359
Economic recovery = 0.55

Late Water Breakthrough – little oil production after, more oil left behind longer term

INTERMEDIATE WET:

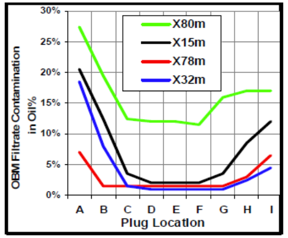
Ultimate recovery = 0.71
Sor (@ fw = 0.95) = 0.476
Economic recovery = 0.44

OIL WET:

Ultimate recovery = 0.78
Sor (@ fw = 0.95) = 0.623
Economic recovery = 0.31

Early Water Breakthrough – more oil production after, less oil left behind longer term

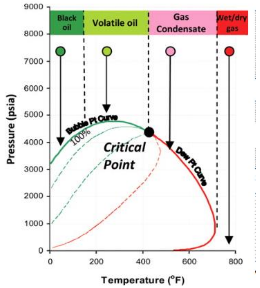
Core “Original” Alteration Sources



Coring Mud Filtrate Invasion

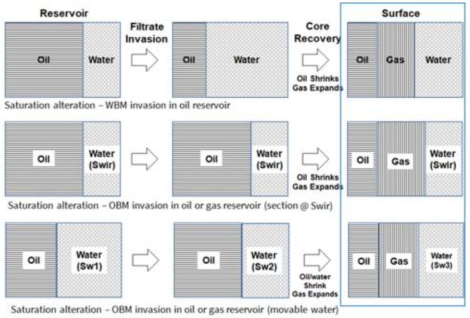
Exposure to Air (oxidation)

Core at surface



Pressure and Temperature Reduction
(impact on fluids)

Saturation History
(fluids coming in and out)



Alteration Analogy

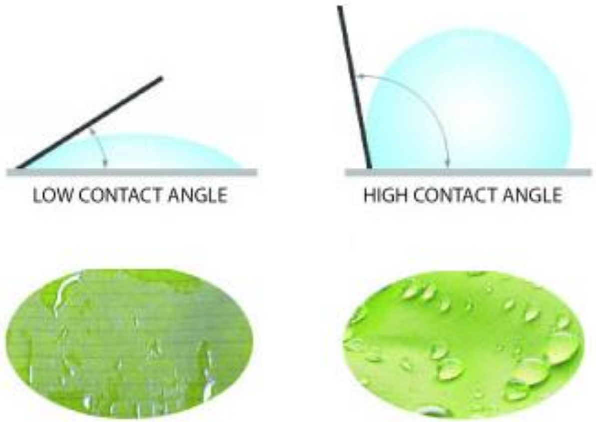
- "Natural" Factors:
  - Relative humidity
  - Temperature
  - Exposure to light
  - Dust
  - Dirt
  - Insects / rodents
- Human mishandling

- Blemishes
- Scratches
- Cracks
- Discoloration

Ecce Homo by Elías García Martínez (1930), Borja, Spain

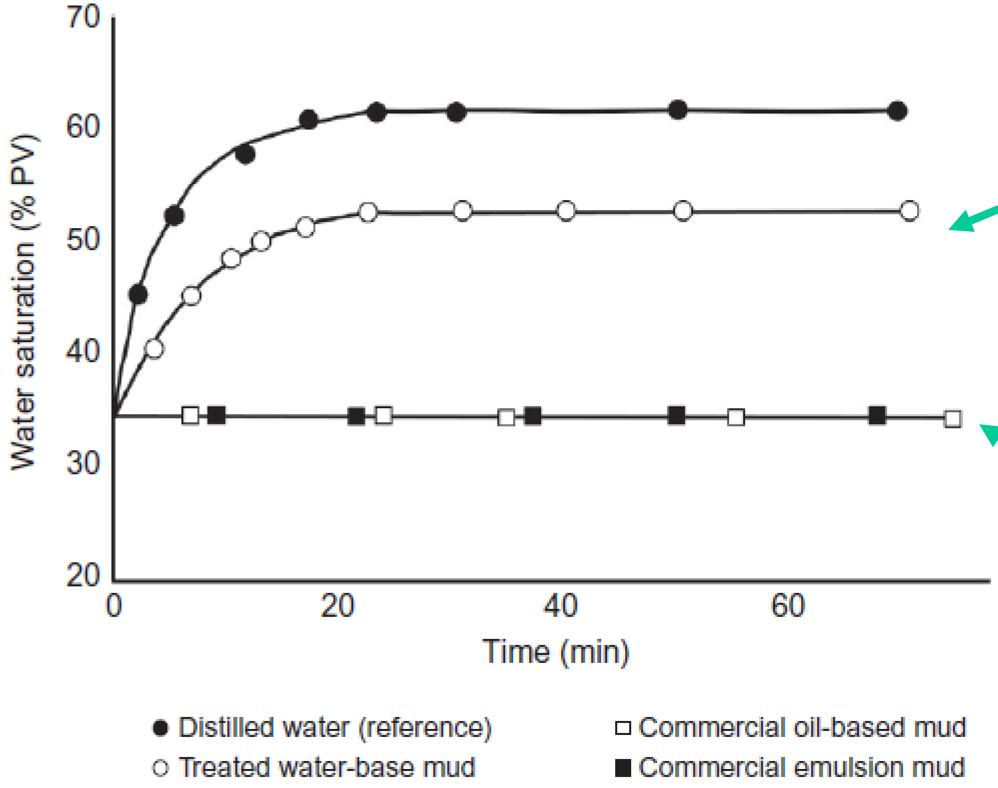
Mud Filtrate Invasion Wettability Alteration

- Components of drilling muds can alter wettability
- Ideal mud → no surfactants - minimum of additives
- Degree of mud-filtrate invasion depends on:
  - Coring bit design
  - Drilling parameters
  - Mud rheological properties
  - Mud cake
  - Rock properties: porosity, Pc, wettability, Ka and Kr
- $CaCO_3$ filter cake → may help minimise mud filtrate invasion
- Adding tracer to mud → helps quantify potential filtrate invasion



- In reality:
  - Oilfield chemicals used routinely in coring → sometimes for good reasons
  - Well control / HSE → take precedence over bland coring mud requirements
  - Wettability alteration may be severe for SBM:
    - emulsifiers for water phase and strong oil wetting agents to keep clays, barite and cuttings oil wet and in suspension
    - contact with SBM is known to induce a strong oil-wetting tendency → difficult to remove

Mud Filtrate Invasion Wettability Alteration



Bobek, et al. (1958)

- Water-Based Mud
  - strong water imbibition
  - water-wet
- Oil-based/Emulsion Mud
  - no water imbibition
  - not water-wet
  - alters “native” wettability

Assessing Mud Filtrate Invasion After Coring

- **Tracers:**
  - Requires planning before coring
  - Added to mud system to distinguish invasion
  - WBM: D2O, tritium, NaBr, etc
  - OBM: Bromonaphthalene, Deuterated hydrocarbons and paraffins

- **Analytical Geochemistry:**
  - Uses inherent mud components as "natural" tracers

- **Visual inspection**
  - Merely qualitative
  - At wellsite/lab arrival end of barrel mud invasion ring inspection (may diffuse with time - documented with photographs). Not always obvious
  - Slabbed core UV light images (as soon as possible after core arrival at lab)

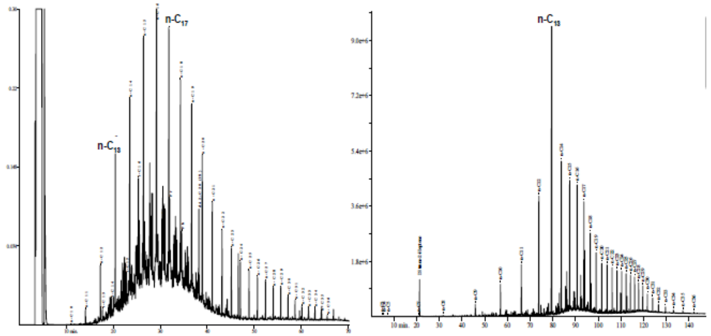
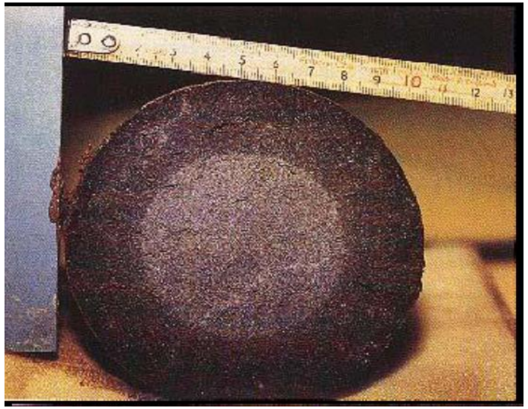
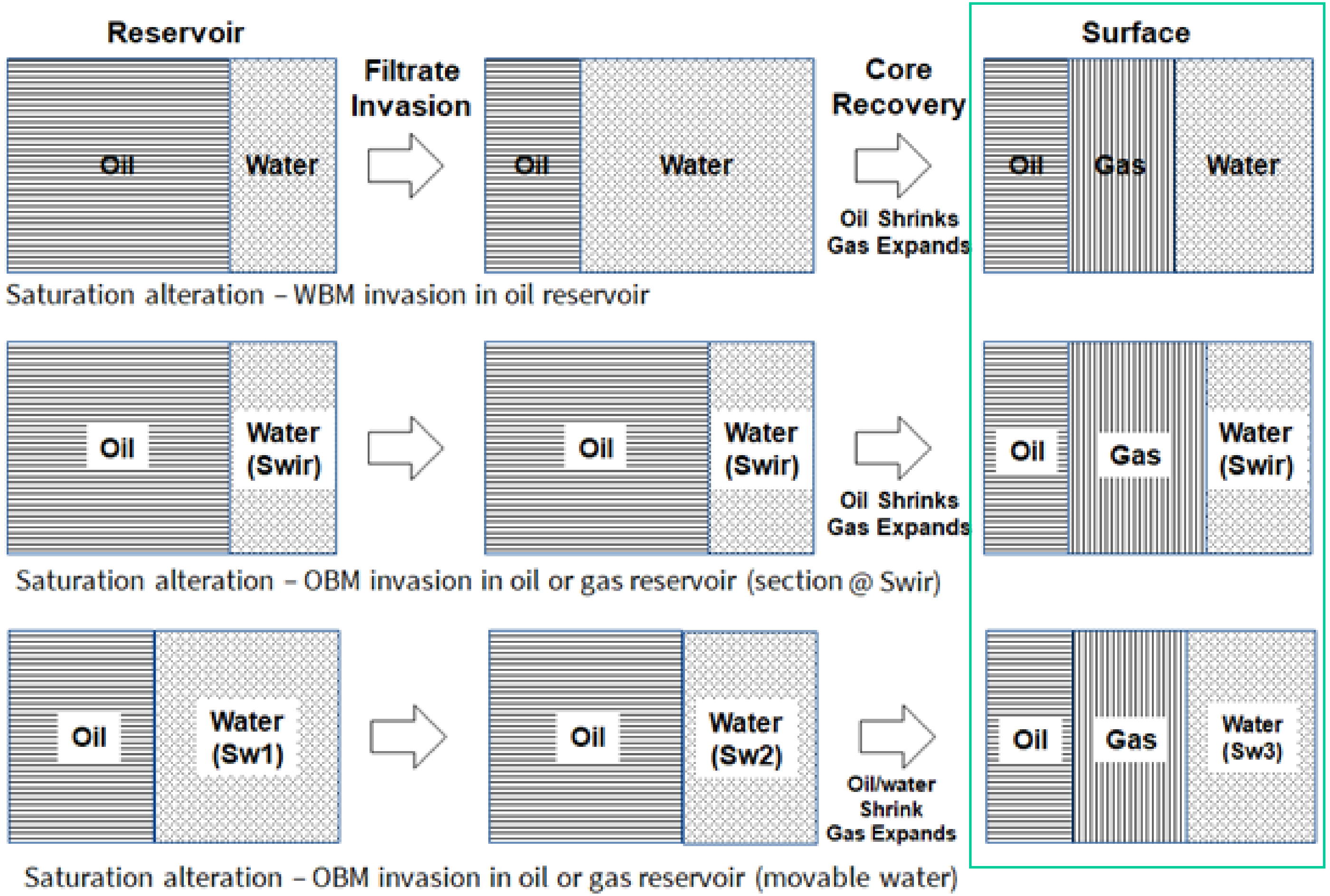


Figure 3: GC of core extract from well A1 (left) and centrifuged fluid from well C2 (right). MF is calculated as 74 and 29 %, respectively. In the latter case some influence of Clairsol is also seen (calculated to 14 %).

SCA2016-032: QUANTIFYING MUD CONTAMINATION WITHOUT ADDING TRACERS. K.S. Årland, OREC AS and M. Bastow, APT AS



"True" Reservoir Fluid Distribution Alteration



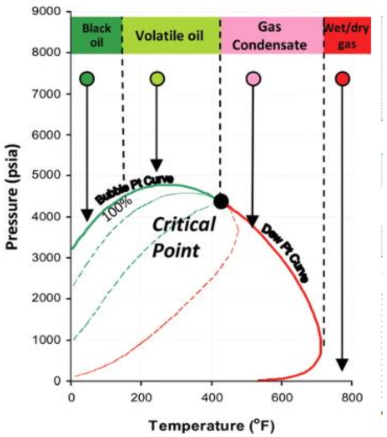
- "Fresh-State" status of samples when received in the lab
- Are they representative of the reservoir?

Swir trapped by capillary forces unless IFT is altered (surfactants)

Best case scenario to start a typical lab Wettability test, provided the mud filtrate has not altered Native wettability

Challenge: most OBM now days contain a water phase 10 – 40 % of the total mud volume !!!! Tracers required, even in OBM

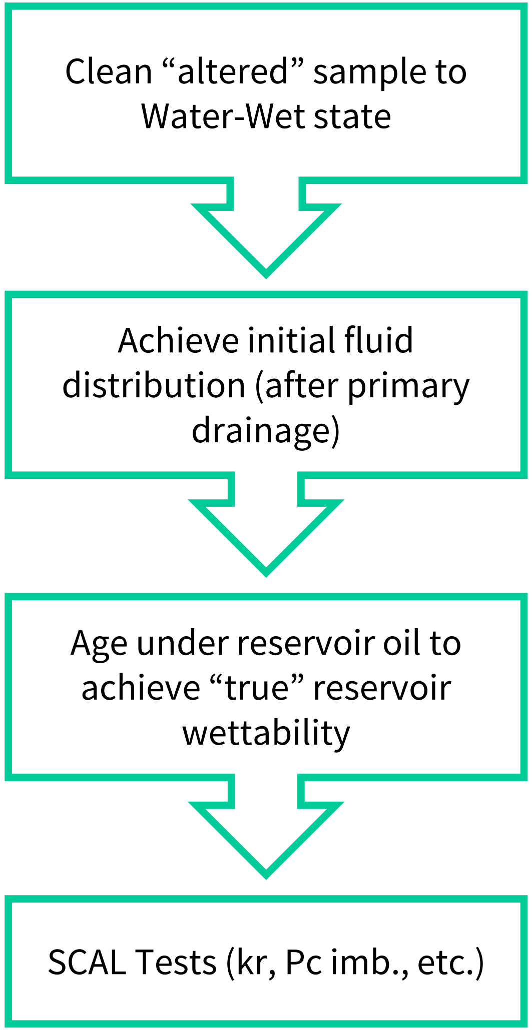
Pressure and Temperature Wettability Alteration



- P and T reduction → gas released as core retrieved
  - Relative concentration of heavier end components and surfactants → increases
  - Asphaltene and wax components of oil → can precipitate
  - Solubility of surfactants in the oil → reduced
- Consequence → rock can be made more oil wet (or less water wet) (adsorption oil wet components)
- Oxidation of crude oil through core exposure to air (rig/lab) → can induce a less water-wet tendency
  - Correct core preservation before testing important

Wettability Alteration

- **Accept wettability alteration**
- **Restore wettability**
  - recreating reservoir history in hours
    - cleaning to remove native oil and mud contaminants to achieve water-wet condition (reservoir before hydrocarbons)
    - oil migration (Swi)
    - ageing → re-establish equilibrium between rock and reservoir fluids



Preserving Rock Surface Morphology During Preparation

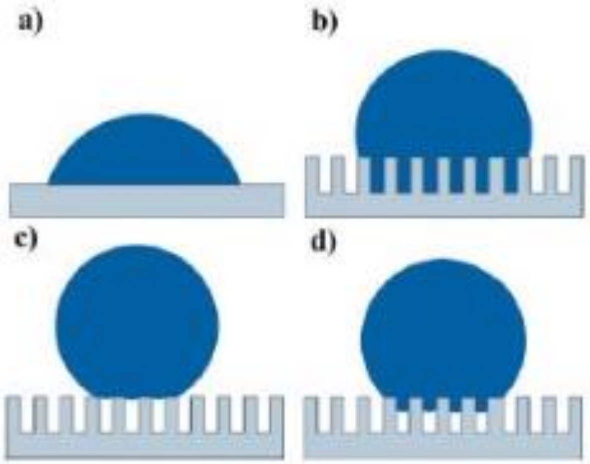


Figure 2. Effect of surface structure on the wetting behavior of solid substrates. a) A liquid drop on a flat substrate (Young's mode). b) Wetted contact between the liquid and the rough substrate (Wenzel's mode). c) Non-wetted contact between the liquid and the rough substrate (Cassie's mode). d) Intermediate state between the Wenzel and the Cassie modes.

Source: Feng et al., *Adv. Mater.*, **18** (2006), 3036-3078

- Alteration of surface roughness also affects the way fluids interact with the rock
- Surface alteration will affect the final wetting tendency and maybe irreversible
- Important to preserve the pore surface structure (clays)
- Key consideration in core preparation process

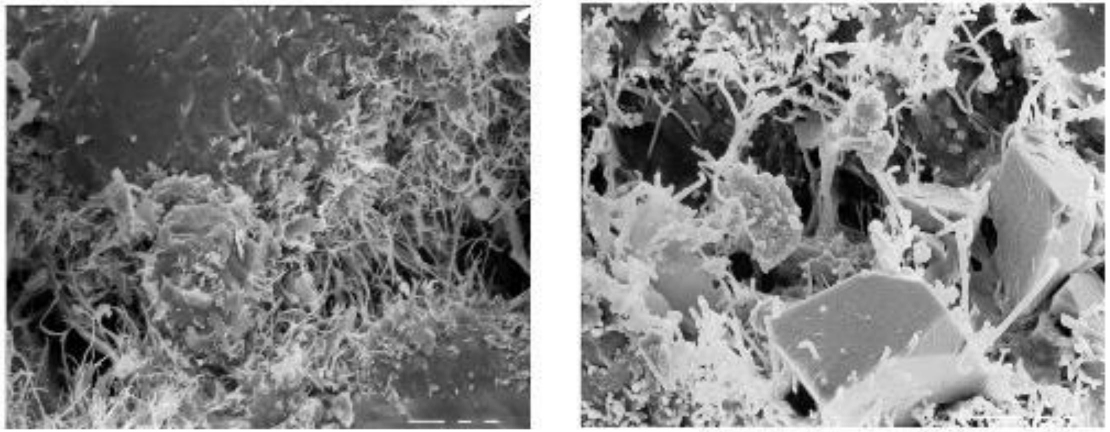


FIGURE 4.22 SEM photomicrograph indicating damage to illite on evaporative drying. *From Byrne and Patey (2004).*

Achieving Representative "Clean State" Samples

- Core Cleaning Objective: remove oil + water + other contaminants, preserving the rock fabric
- Should render core samples water wet
- Water wet condition is a pre-requisite for:
  - Wettability restoration (prior to Kr, Pc imb., wett. Tests)
  - Tests involving a primary drainage cycle
- Solvent flush (core holder) and total immersion cleaning → proven effective in removing contaminants, preserving clays
  - Harsh cleaning may remove clay bound water, inducing an oil-wet tendency:
    - Polar oil fractions get access to the rock surface
    - Exacerbated by low initial Sw, long term storage and exposure to air (oxidation)
  - In some cases, extremely harsh cleaning methods and solvents may be required, which balances against the need to preserve the rock's fabric
  - In any case, the results of the cleaning procedure need to be checked by performing wettability tests in what is believed to be a "Clean-State" sample

Achieving Representative Initial Fluid Saturation

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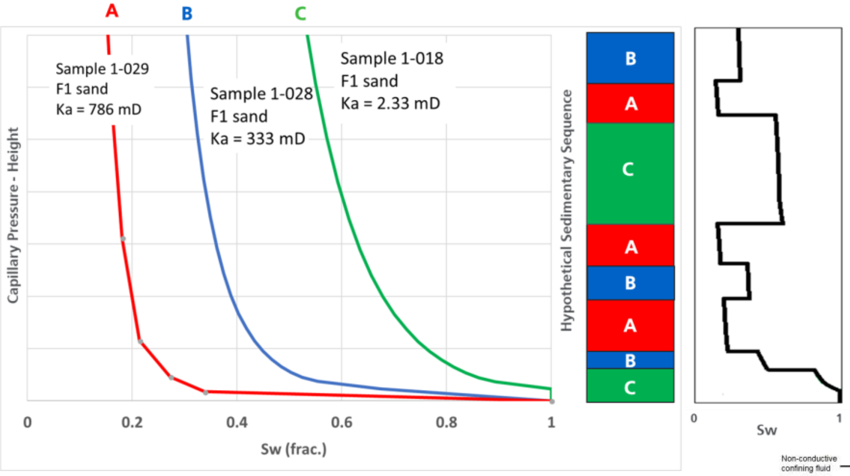
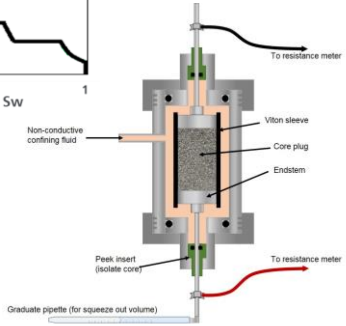
Swi pre-ageing representative of:

- Rock quality
- HAFWL

Requires early input from Sw. vs. H





- **Centrifuge**
  - May not be suitable for delicate samples (tend to fracture)
  - Relatively fast. Preferred method is sample allows (weeks)
  - Samples should be allowed for the non-uniform saturation profile to equilibrate
- **Dynamic Displacement (core holder)**
  - Forces may be too low to achieve target Swi (Sw is normally too high)
  - Applied pressure to achieve Sw is normally not reported
- **Porous plate**
  - Best method as uniform saturation can be achieved
  - Very slow compared to other options (months)

Ageing Time and Fluids for Wettability Restoration

- **Ageing time**
  - How long?
    - 6h, 6d, 14d, 28d, 40d (1000h), more? Standard is 40 days (always debatable this is enough to mimic millions of years of oil accumulation. Changes for each reservoir)
- **Ageing oil**
  - Oil samples taken by wireline are often contaminated by wettability altering mud filtrate
  - No reservoir oil available (or not enough) in some cases
  - Use of analogue oils is sometimes the only alternative
- **Ageing process**
  - Dead or live oil ageing? Depends on the nature of the oil. GOR $<$ 200 scf/bbl (40 m3/m3) is normally regarded as not requiring life oil ageing
  - Dead ageing (most common) – batch (no injection – can't quantify production)
  - Dead ageing – injection (1 PVI STO/ week) – oscillating direction
  - Live ageing – injection (1 PVI STO/ week) – oscillating direction
    - Expensive, requires skilled lab to recombine the oil (good PVT), prompt to leaks, not all labs have the required capabilities

Successful Restoration?

Initial – Unaltered State

Alteration

Altered State

Restoration

Restored State ??

Elías García Martínez, *Ecce Homo* (1930), and Cecilia Giménez’s infamous 2012 restoration attempt

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