Impact of Wettability on Our Business: *Field Scale Applications*

James J Howard

Wettability Workshop
SCA-2018 Trondheim

Wettability Issues at the Field Scale

How to Translate Pore-Scale Phenomena to the Reservoir Scale?

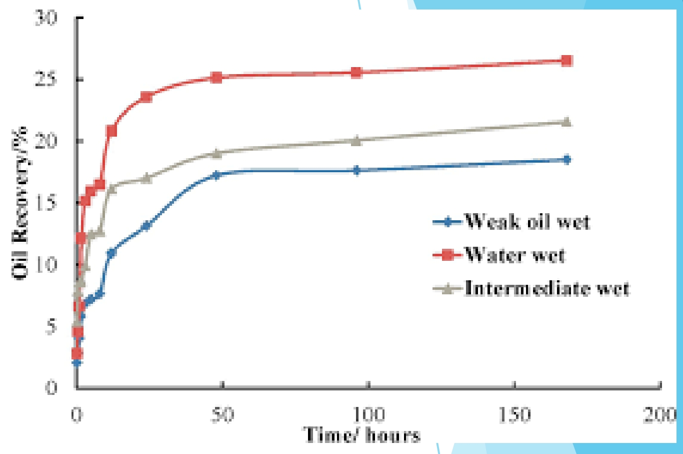
- Wettability Distributions in Conventional Reservoirs
- Impact of Wettability Information on Field-Scale Operations
  - Production in Transition Zones
    - Impact on Swi - Sor and Recovery Efficiency
  - Design of EOR Projects – Waterflood, Polymer
  - Gas Reservoirs – Condensate Blocking
- How is Wettability Information Incorporated into Reservoir-Scale Simulations
  - Role of Fractional Flow

Historical Evaluation of Wettability

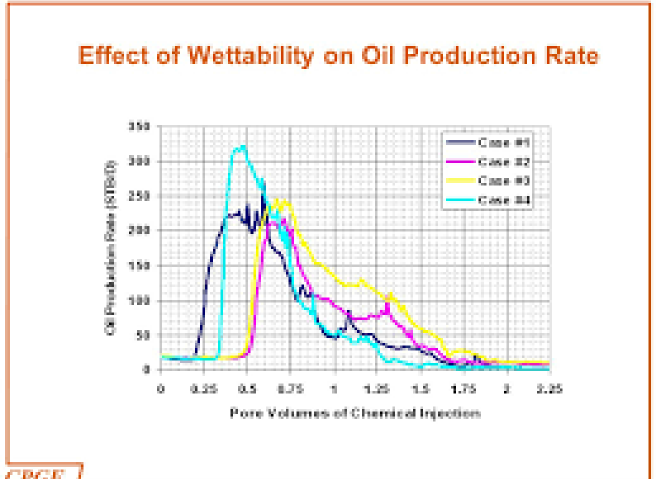
- Original Water Wet (Leverett, 1941) in Reservoir Rocks
  - Source Rock “Assumed” Oil-Wet
- Carbonates –
  - Oil Wet (Treiber, 1972; et al.)
    - *Contact Angles – Reservoir Crude at Temperature, Idealized Surfaces*
    - *Morrow (1976) Re-Interpreted Data – Intermediate Wetting*
  - Mixed Wet (Cuiec et al; 1990s)
  - Weakly Water-Wet to Mixed-Wet (Morrow, 1990)
    - Crude Oil Interactions (COBR)
- Today’s Consensus?
  - Recognize Critical Steps Required to Transform a Reservoir to Oil-Wet Conditions
  - Importance of “Shale” Reservoirs

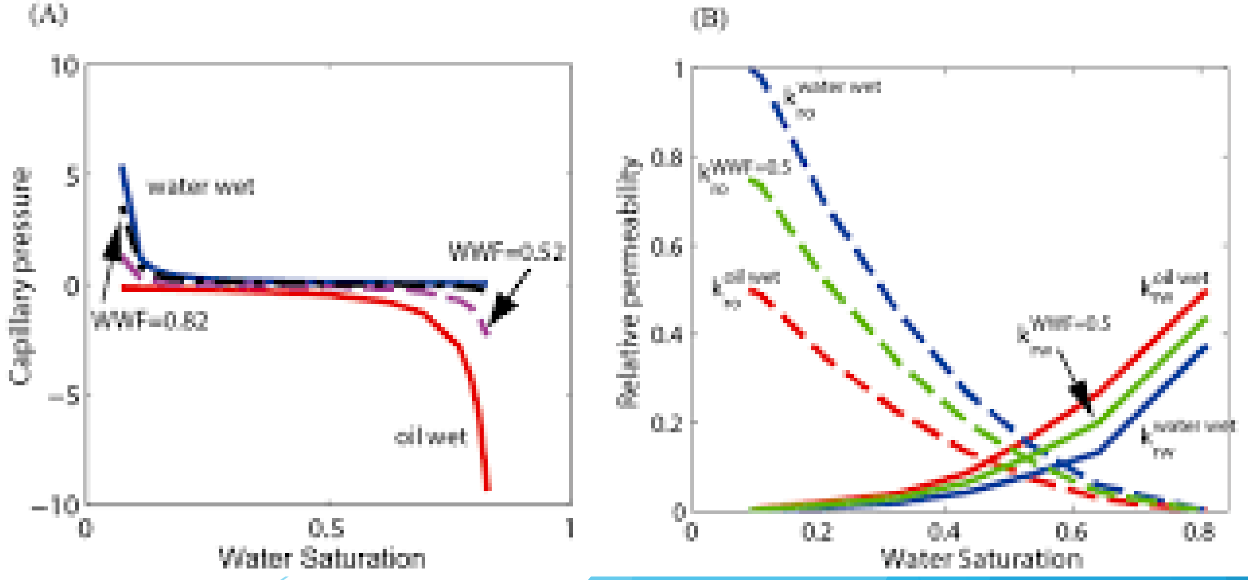
How to Determine Wettability at Field Scale

- Borehole Measurements
  - Wireline Logging Tools
    - Note that Most Electric Log Interpretation is Successful with Default Archie Parameters (n=m=2.0) – *Suggestive of Water-Wet Fluid Distributions in Pores*
    - Dependent Upon Core Measurements to Assign Properties for Field Evaluation



- Shape of Recovery Curves

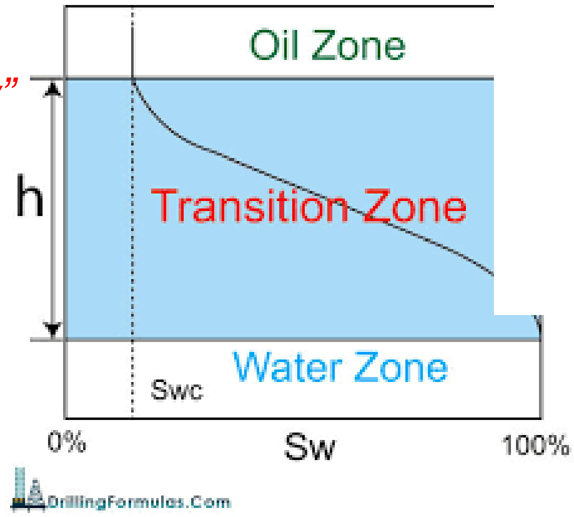


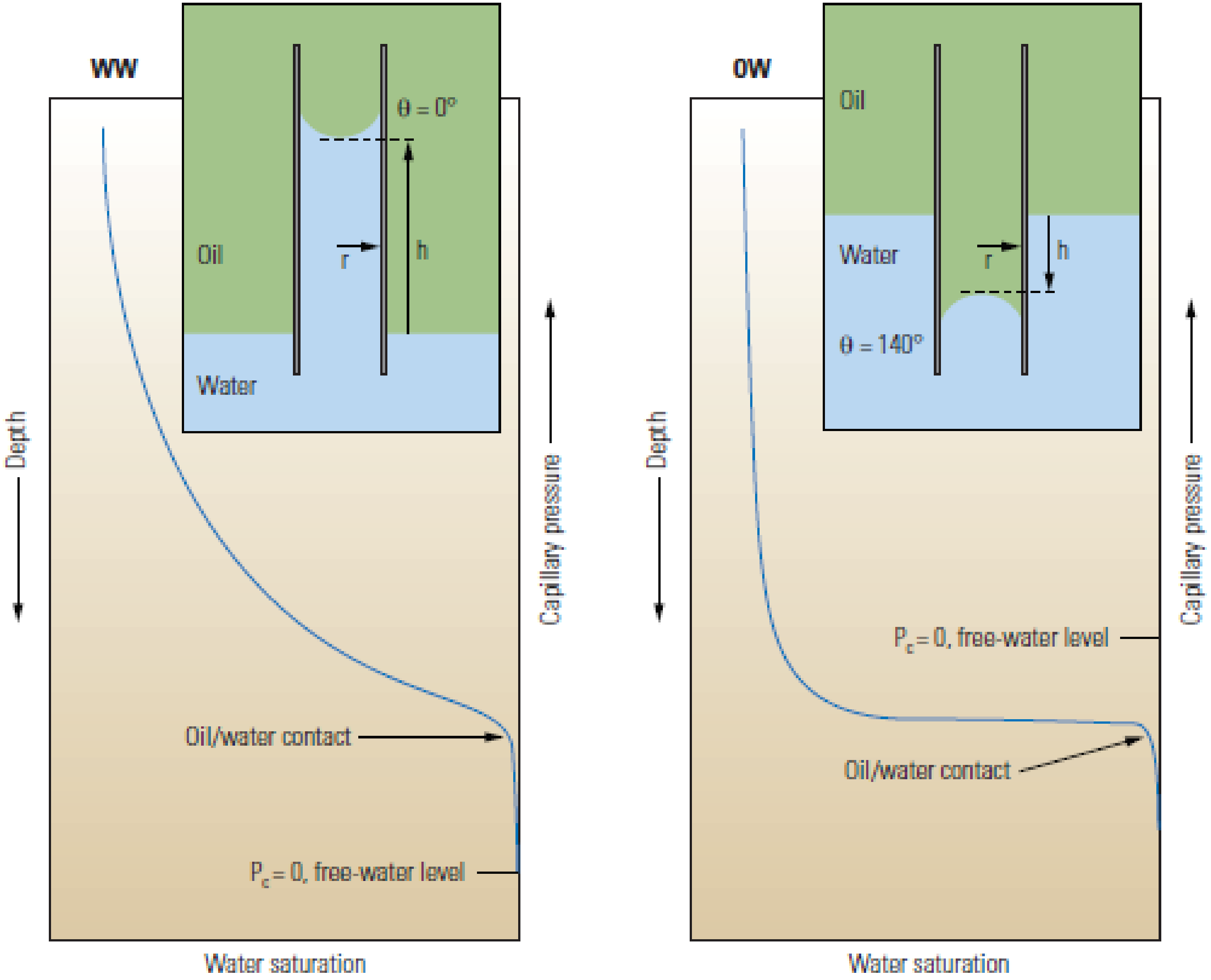


Vertical Distribution

- Trends with Depth that Follow Fluids Distribution
- Focus on Transition Zone
  - Distinguish Microscopic Wetting Features from Larger Scale Pore Geometry
  - Sandstone Reservoirs (Hamon, 2000)
  - Ekofisk (Hamon, 2004; PPCo Internal)

Oil Zone "Potentially" Oil-Wet



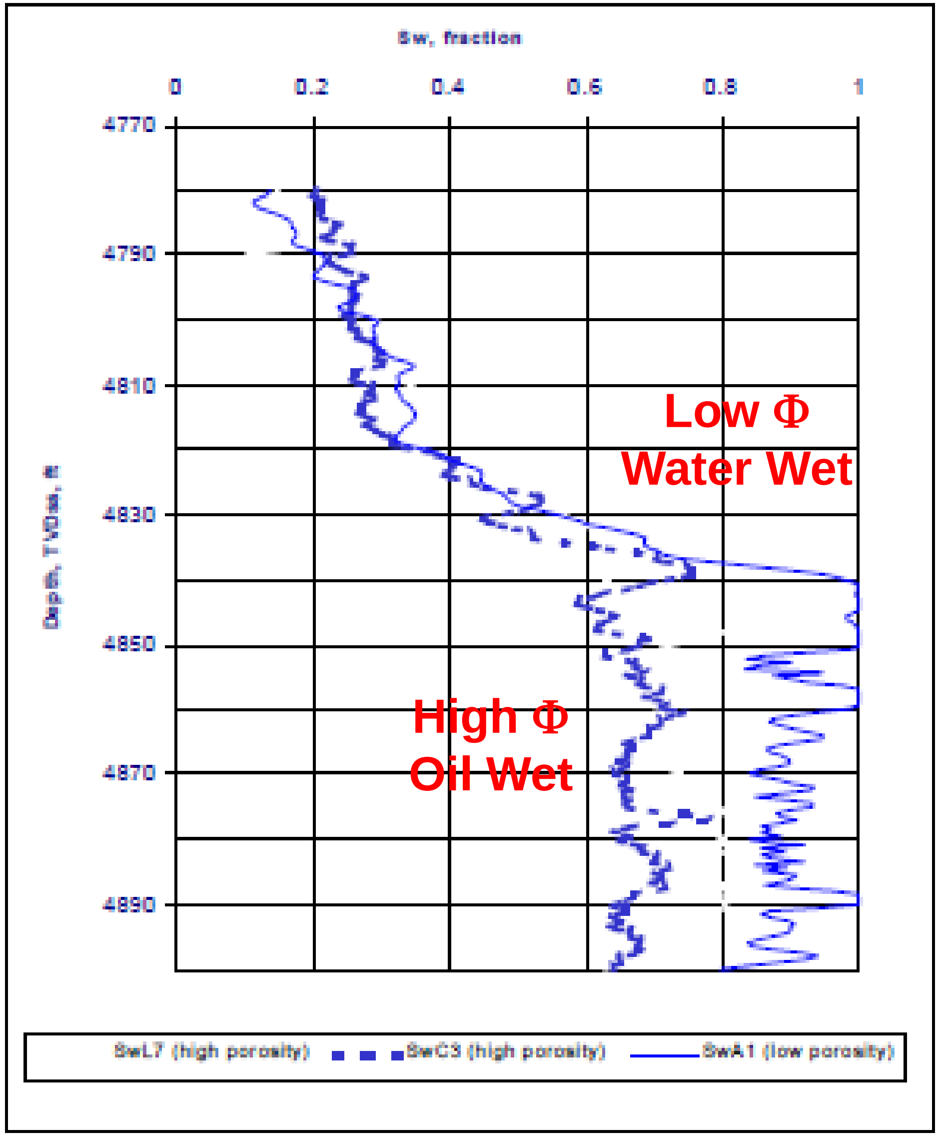


Idealized Transition Zone Thickness Relative to FWL

Oil Field Review, Summer 2007

Vertical Distribution

- Transition Zone Influenced by:
  - Capillary Effects – Pore Size
  - Fluid Distributions – Wettability
- Example of “Mixed-Wettability”
  - Large Pores – Oil Wet
  - Small Pores – Water Wet
- Transition Zones
  - OW – Narrow
  - WW - Broad



Nubian Sandstone, Offshore Egypt
Elshahawi, et al, 1999

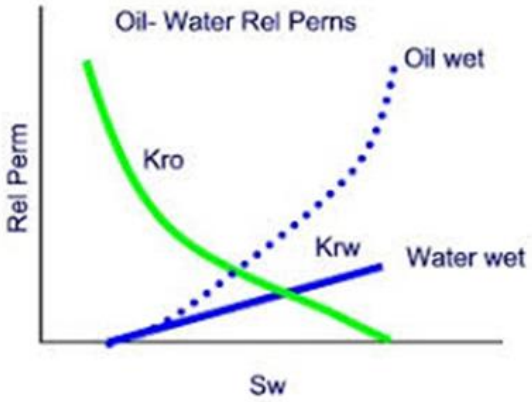
Sw-Height Curves

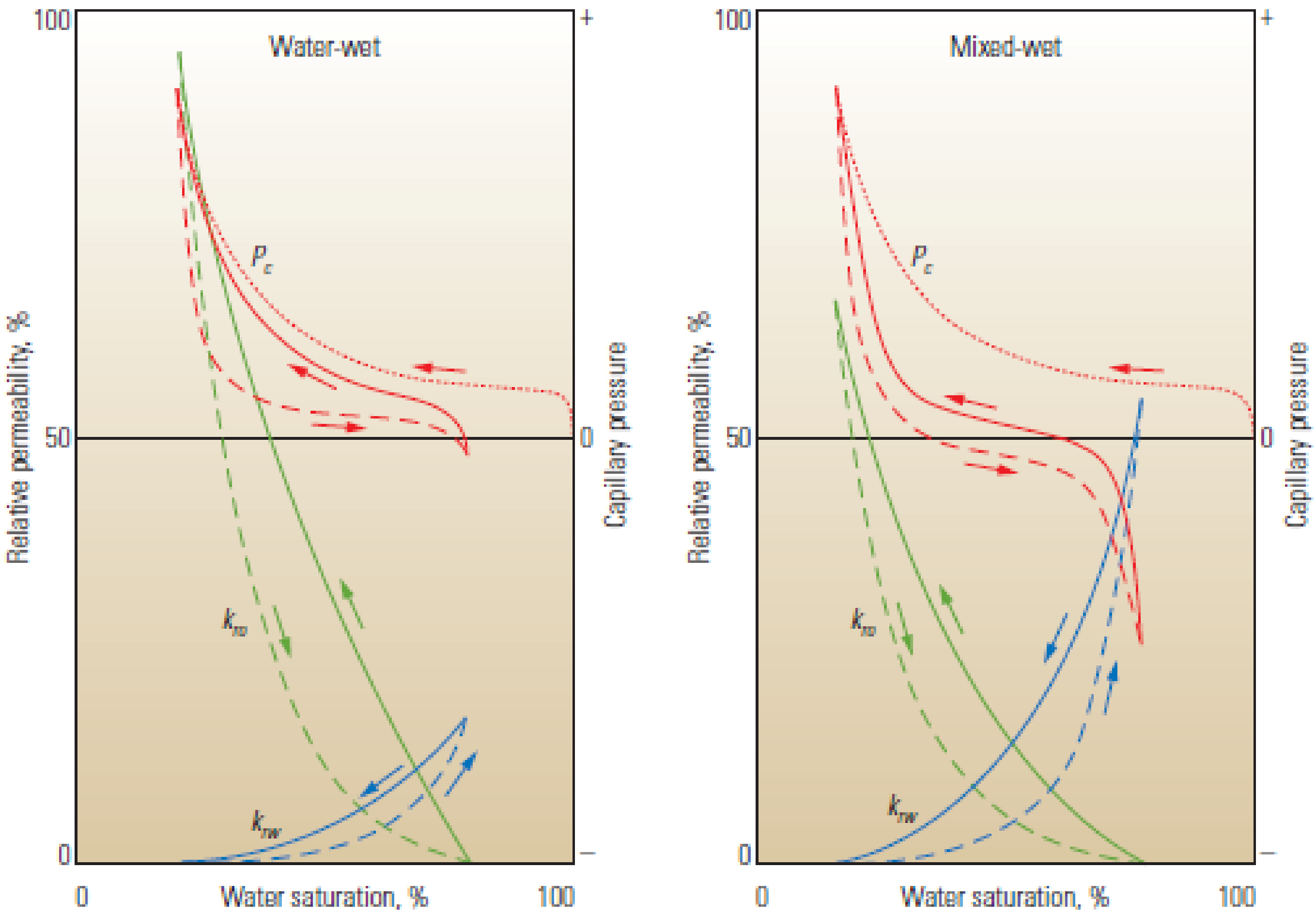
Areal Distribution

- Areal Distribution of Wettability Generally Follows Structural Trends
  - Up-Dip vs Down-Dip
  - Changes in OWC/FWL During Basin History
- Few Reliable Studies that Match Wettability Variations with Lithology
  - North-Sea Sandstone (Hamon, 2000)
  - Higher Permeability Layers with Larger Pores Have Stronger Mixed-Wet Character
  - Lower Permeability Layers Tend to Slightly More Water-Wet
- Generally Not Enough Samples in a Field to Validate Basic Model

Relative Permeability and Capillary Pressure Curves

- Capillary Pressure
  - Imbibition End-Point
  - Negative Pc
  - Hysteresis
- Relative Permeability
  - End Points
  - Water Permeability

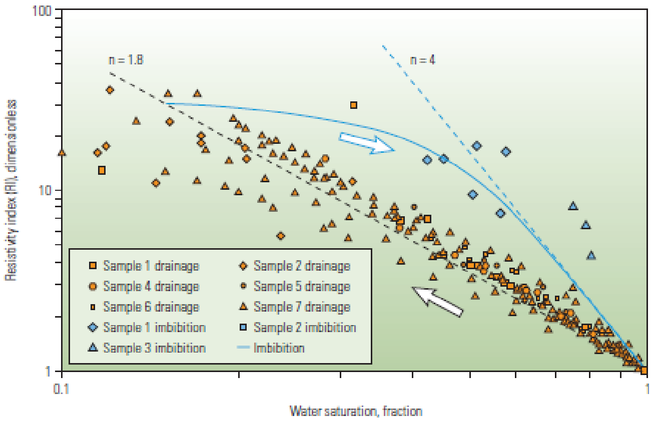




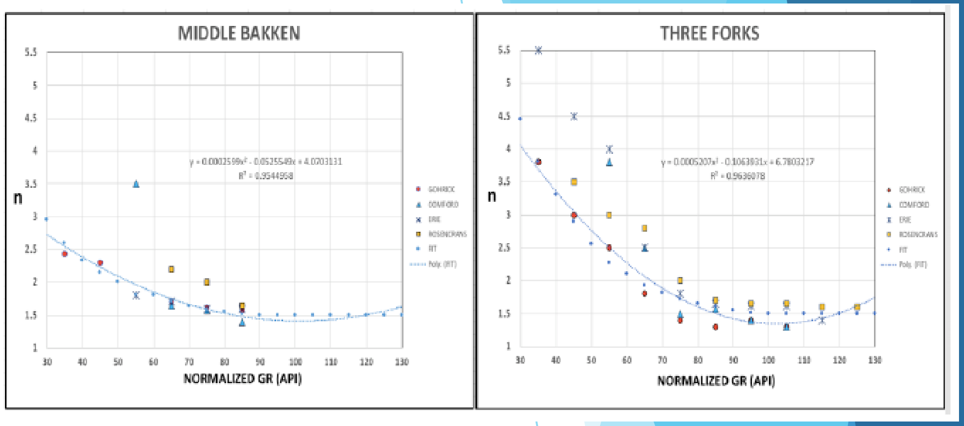
Oil Field Review, Summer 2007

Field Scale Measurements

- Wireline Measurements
  - Formation Testers (Pressure)
  - Electrical
  - NMR



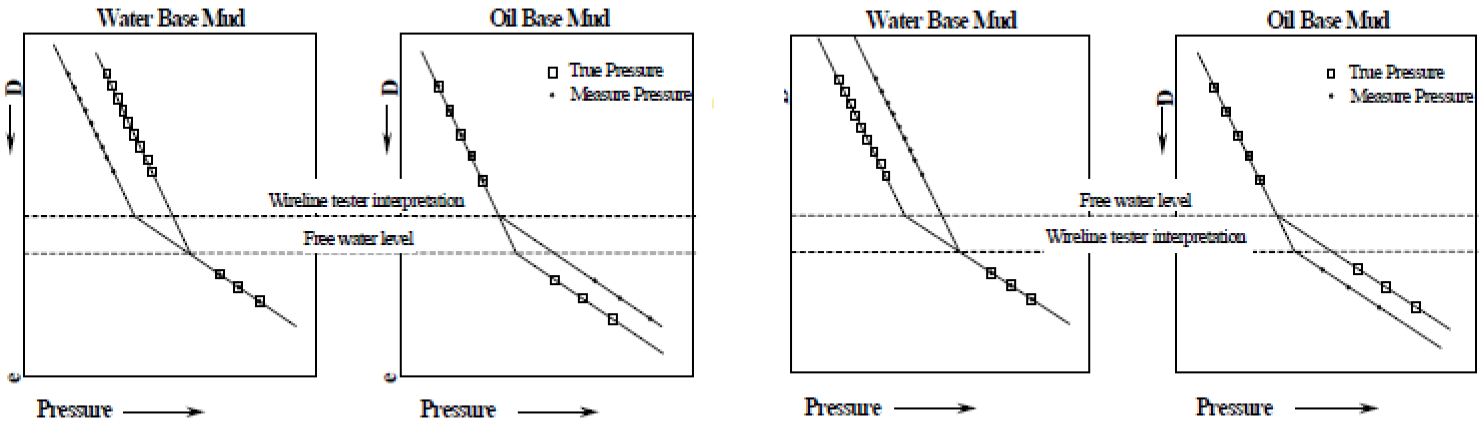
Lab Measurements Used to Define Archie Parameters



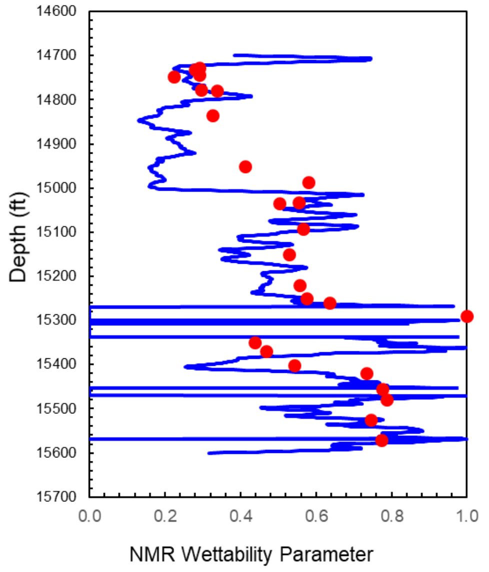
Variable "n" in Dolostones, Merkel et al., 2018

Water Wet

Oil Wet



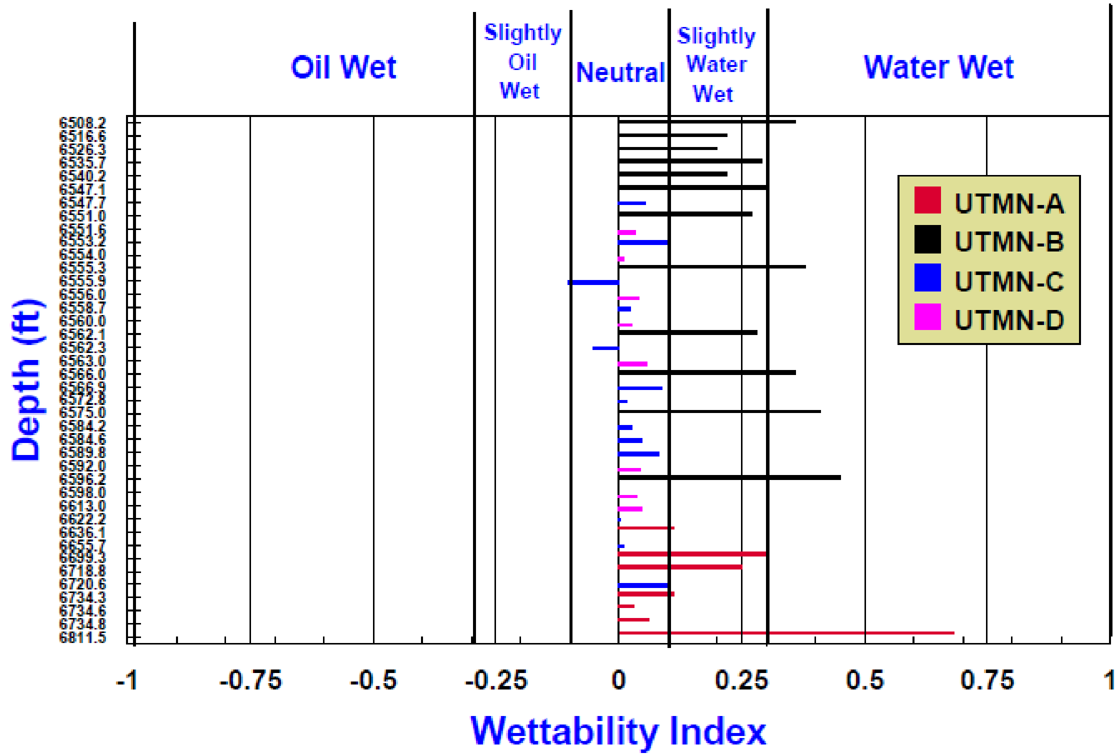
Formation Tester – Elshahawi, et al, 1999



Ekofisk MRIL-Based Wettability ~1996
PPCo Internal Report

Wettability Alteration During Life of Reservoir

- Waterflood Response
  - Standard
    - Trend Towards More Water-Wet with Prolonged Water Injection
  - Low-Salinity
    - More Water Wet (BP)
    - More Oil Wet (Statoil)
- Arab-D Case History
  - Early Production (56-69)
    - Mildly Water-Wet (high pH Drilling Fluids)
  - Late Production – Waterflood (2000-12)
    - Neutral to Mildly WW

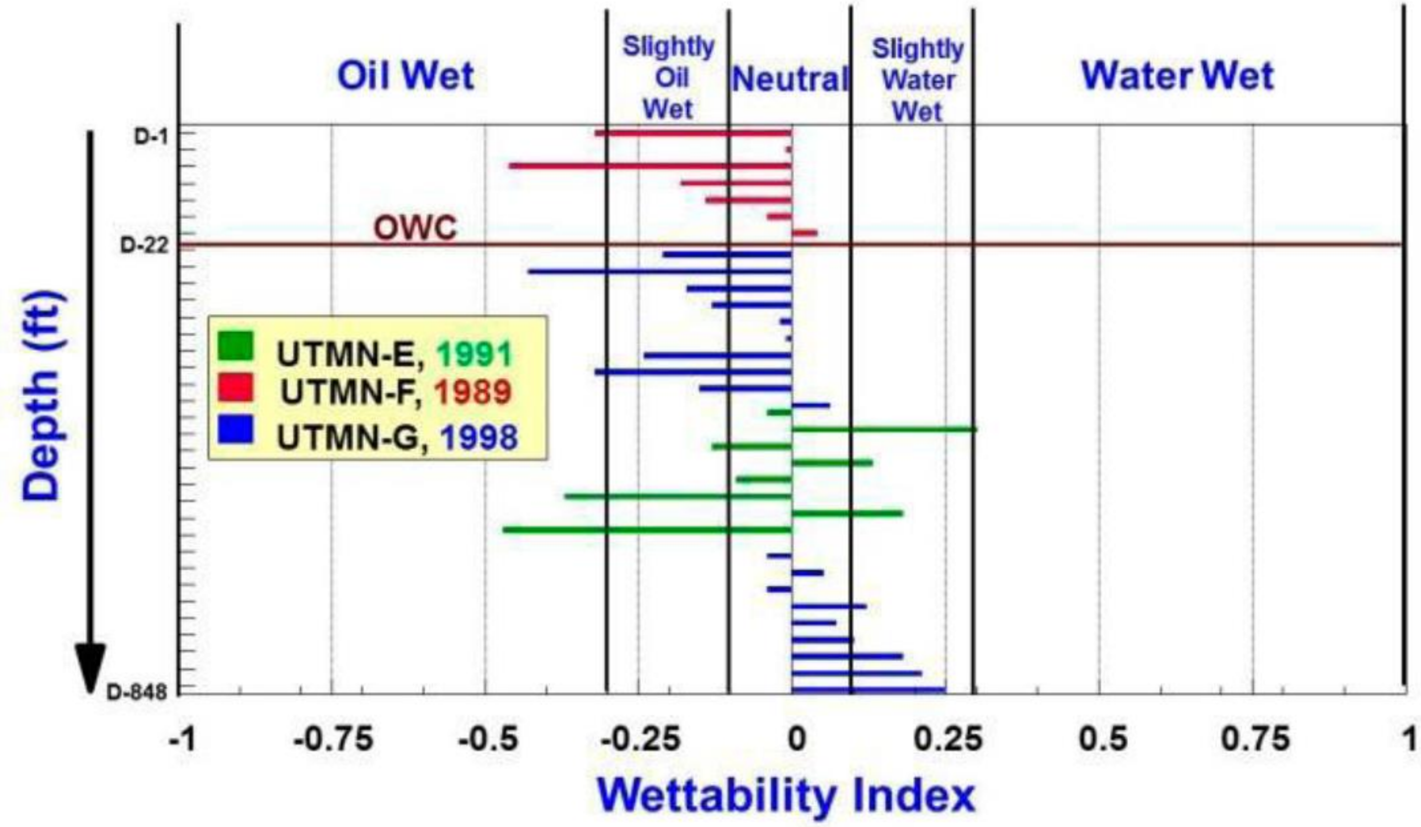


Amott Indices, Four Late-Stage Production Wells, Uthamaniyah Area (~2005)

Okasha, 2014, Wettability Evaluation of Arabian Carbonate Reservoir after Prolonged Water Injection; SPE 105114, 2007

Wettability: Life of a Reservoir

- USBM Wettability
- Arab-D Uthmaniyah Area
  - Agreement with Other Arab D Studies
- Original Weakly Oil-Wet Reservoir.
- Mild Cleaning – Neutral to Weakly Water Wet
- Restored State – Neutral to Weakly Oil Wet



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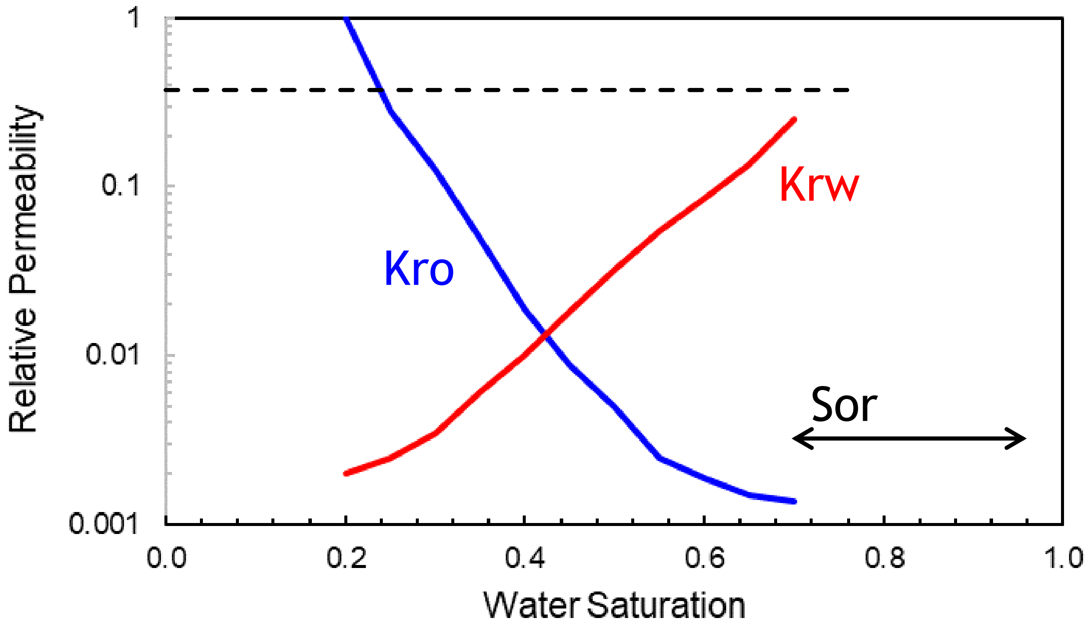
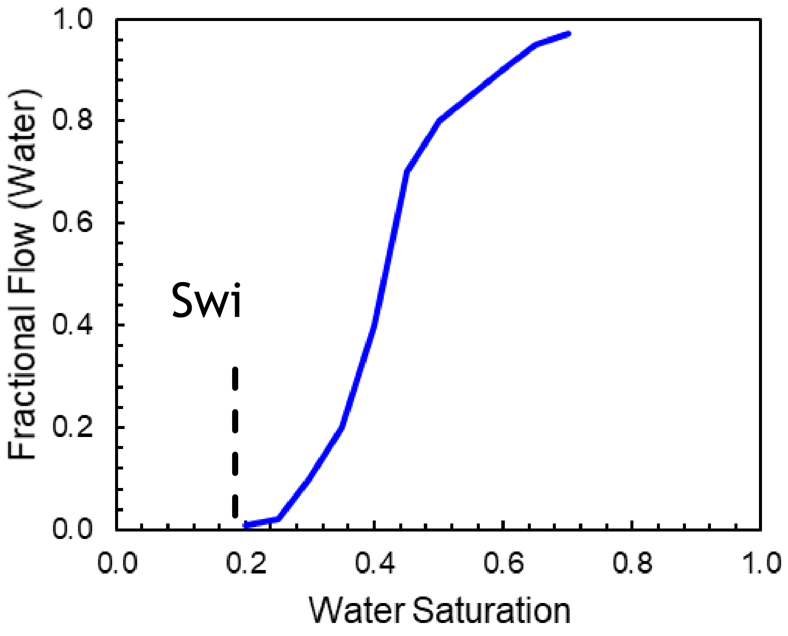
USBM Indices Three Mid-Stage Production Wells. Preserved Core – Stored with KCl Brine

Reservoir Engineering Concerns

- Too Many Pore Volumes of Water Injected in the Laboratory

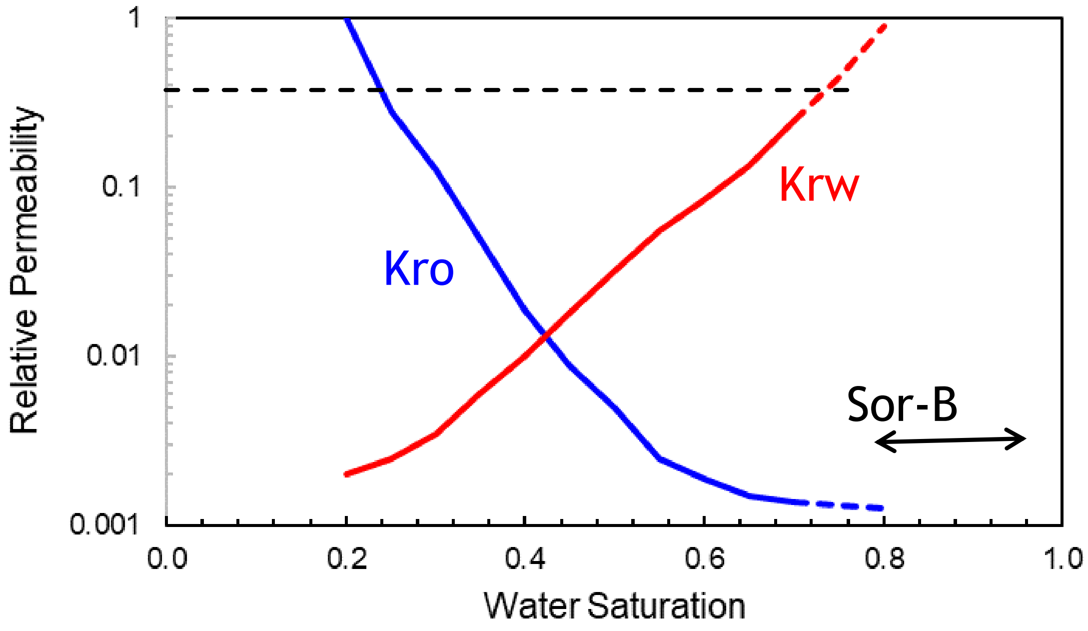


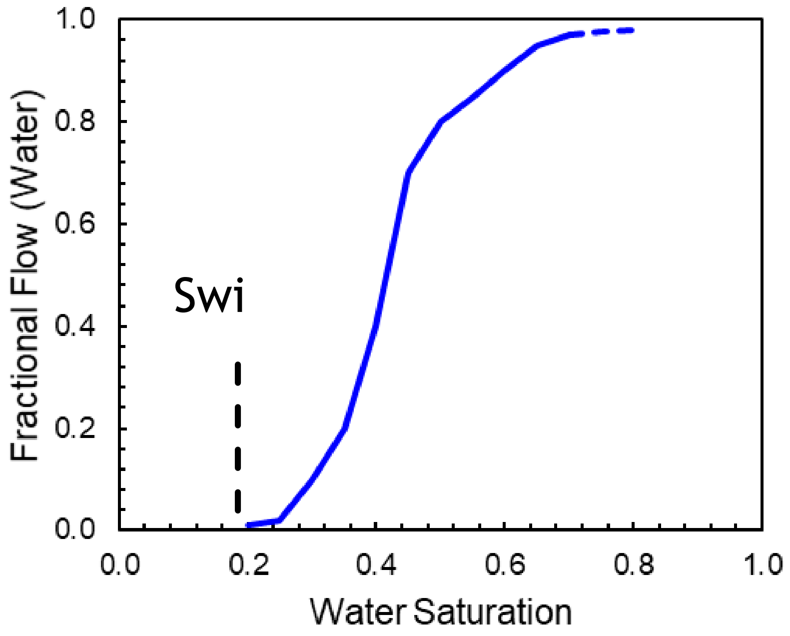


After Dake, 1994, The Practice of Reservoir Engineering

Reservoir Engineering Concerns

- Too Many Pore Volumes of Water Injected in the Laboratory
  - Shift from Water Wet to Oil-Wet (Krw > 0.5)
  - Sor Decreases by 0.10

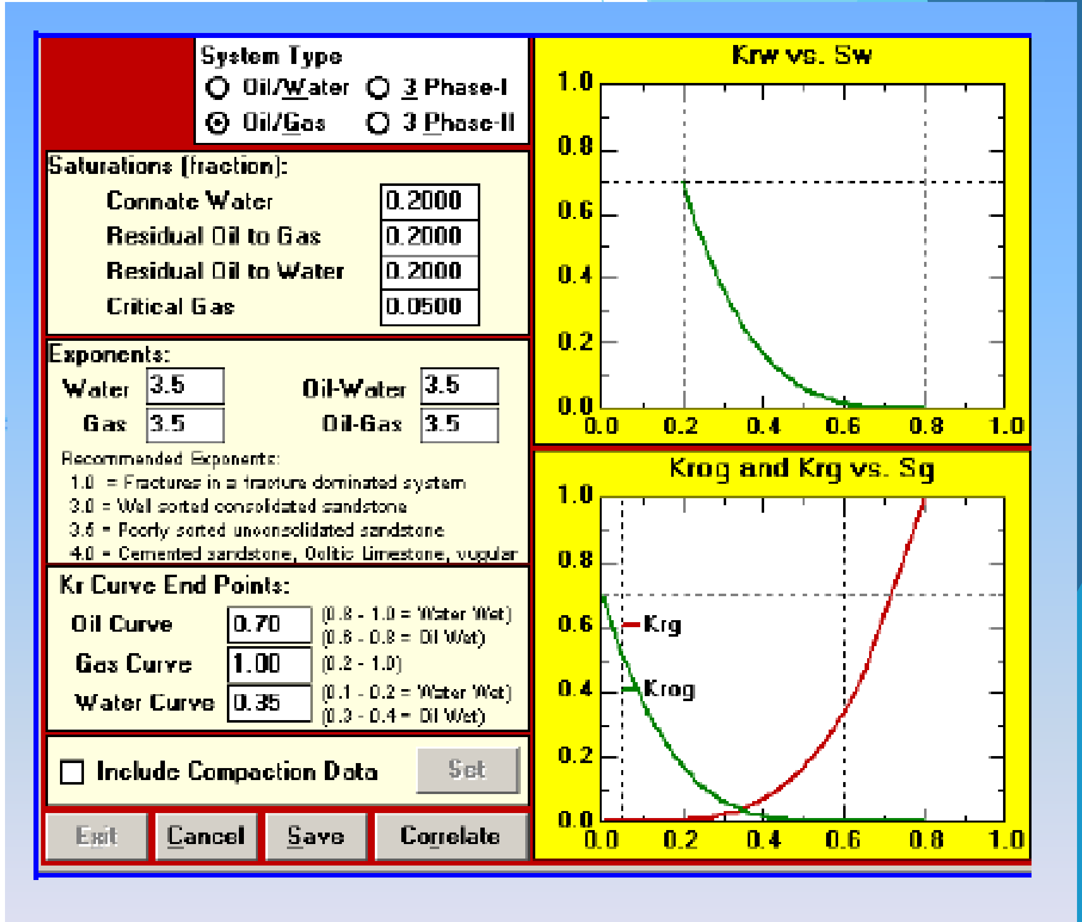




After Dake, 1994, The Practice of Reservoir Engineering

Wettability and Reservoir Simulation

- Simulation Models Do Not Require Input Parameters for Wettability Characterization
- DO Require Swi and Sorw Values
- SOME Require Endpoint Permeability Values
- SOME Use Exponents to Define Shape of Krel Curves



Additional Thoughts

- Reservoir Scale Distribution of Wettability Does Affect Production Performance Throughout Lifetime of Field
- Alteration of Wettability During Production is Likely
  - Changes in Temperature and Pressure Promote Asphaltene/Resin Deposition, Disrupt Equilibrium Conditions
  - Waterflood Strips Organic Residue
- Historically Core Measurements Have Mislead Field Development Planning
- Field-Scale Measurements of Wettability Are Lacking
  - Challenge is to Distinguish Wettability from Capillary-Force Contributions to Petrophysical Properties

Summary

- Field Scale Simulations have NO Interest in Wettability Parameters (e.g. Contact Angles, Amott Indices, etc.)
  - These Models Have Inputs for Relative Permeability and Capillary Pressure End Points
- Left to Their Own Devices, Reservoir Engineers Will ADJUST These Parameters to History Match Production Curves
  - However, Most are Smart Enough to Recognize the Danger in this Approach, So They will Seek Out SCAL Results to "Assist" in the Interpretation
- Challenges for SCAL and Wettability Measurements
  - "As-Received" Core is Subjected to Significant P-T Changes During Retrieval that Deposits Crude Oil Components on Pore Walls
  - "Cleaned" Core Mimics Strongly Water-Wet Conditions, Not a Common Reservoir Condition
  - "Restored-State" Requires Insight to Reservoir Conditions – A Tautological Dilemma!