Abnormal Pressures and Water Saturations in Tight Gas Scenarios*

Marcelo Crotti[1]

Search and Discovery Article #42001 (2017)**
Posted February 13, 2017

*Adapted from oral presentation given at Latin America & Caribbean Region Geoscience Technology Workshop, Buenos Aires, Argentina, November 16-18, 2016

[1]InLab, Buenos Aires, Argentina, South America (mcrotti@inlab.com.ar)

Abstract

Abnormal pressure in tight reservoirs typically indicates that they are not at hydrostatic equilibrium with their environment. Extending non-equilibrium conditions to the reservoir itself gives us a simple explanation for most of the “unconventional properties” usually found in these scenarios. A visual model helps show the equivalence between the over-pressure and the capillary pressure of the system. At the same time, this simple equivalence fully explains the low water saturation and other "anomalies" often found in these reservoirs. Applying this model improves the overall evaluation of these accumulations and improves reserves estimation through direct measurements and modifying the routine use of laboratory capillary pressure curves.

AAPG Latin America & Caribbean Region
ARGENTINA 2016
Geosciences Technology Workshop
Co-hosted by the Argentine Association of Petroleum Geologists and Geophysicists

Abnormal Pressures and Water Saturations in Tight Gas Scenarios

Marcelo A Crotti - Inlab S.A.

Outline

- Characteristics of Tight Reservoirs
- Objectives
- Capillary Pressure Definitions
- A Fundamental Question
- Analysis of a Physical Model
- Conclusions

Outline

- Characteristics of Tight Reservoirs
- Objectives
- Capillary Pressure Definitions
- A Fundamental Question
- Analysis of a Physical Model
- Conclusions

Characteristics of Tight Reservoirs (I)

- Very low Sw when compared with expected values
  - Lab capillary pressure curves suggest gas columns of several thousand feet

    In reservoirs that barely reach a few hundred feet of thickness!
  - Some authors use the term “Sub-irreducible Sw”

- Neither well logs nor well testing suggest significant capillary transition zones

  - While lab curves imply very large transition zones!

Characteristics of Tight Reservoirs (II)

- Very low permeability
- Significant thicknesses
- “Isolated” reservoirs
- Each reservoir seems to have its own FWL
- Over-pressurized systems
- “Anomalous” gradients
- Source rock close to reservoir rock

Outline

- Characteristics of Tight Reservoirs
- Objectives
- Capillary Pressure Definitions
- A Fundamental Question
- Analysis of a Physical Model
- Conclusions

Objectives

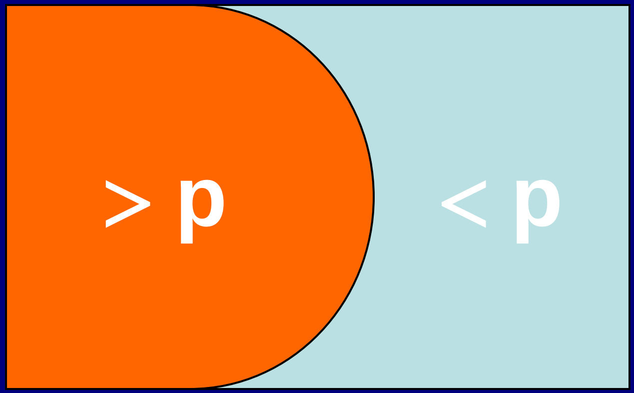
- Get an explanation of the unique characteristics of Tight Gas Reservoirs
- Focus the explanation in water saturation “anomalies”:
  - “Abnormally” low water saturation
  - Absence of capillary transition zones
  - Uncertainties in FWL determination

Outline

- Characteristics of Tight Reservoirs
- Objectives
- Capillary Pressure Definitions
- A Fundamental Question
- Analysis of a Physical Model
- Conclusions

First Definition

- $P_c = p_{nw} - p_w$ [1]



  - Where
    - P_c = Capillary pressure
    - p_{nw} = Non-wetting phase pressure
    - p_w = Wetting phase pressure

- This is the "strict" definition of capillary pressure

First Definition Applicability

- It is always valid
  - At equilibrium conditions
  - During dynamic displacement

But…

- It does not involve usual reservoir or rock parameters
  - Difficult to be used in reservoir calculations

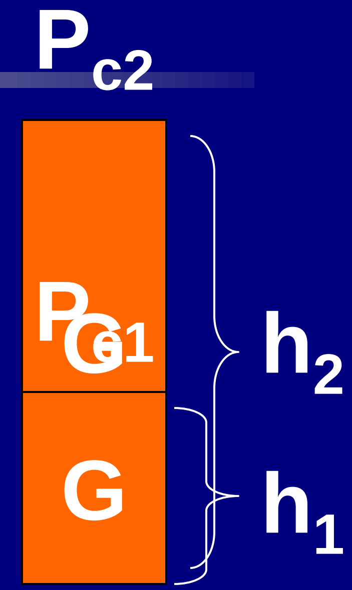
Second Definition

- $P_c = (\rho_w - \rho_g).\ g\ .\ h$ [2]

  – Where:

    - P_c = Capillary pressure
    - $(\rho_w - \rho_g)$ = Density difference
    - g = Gravitational acceleration
    - h = Height of the fluids interface above FWL

- This is the "hydrostatic" definition of capillary pressure



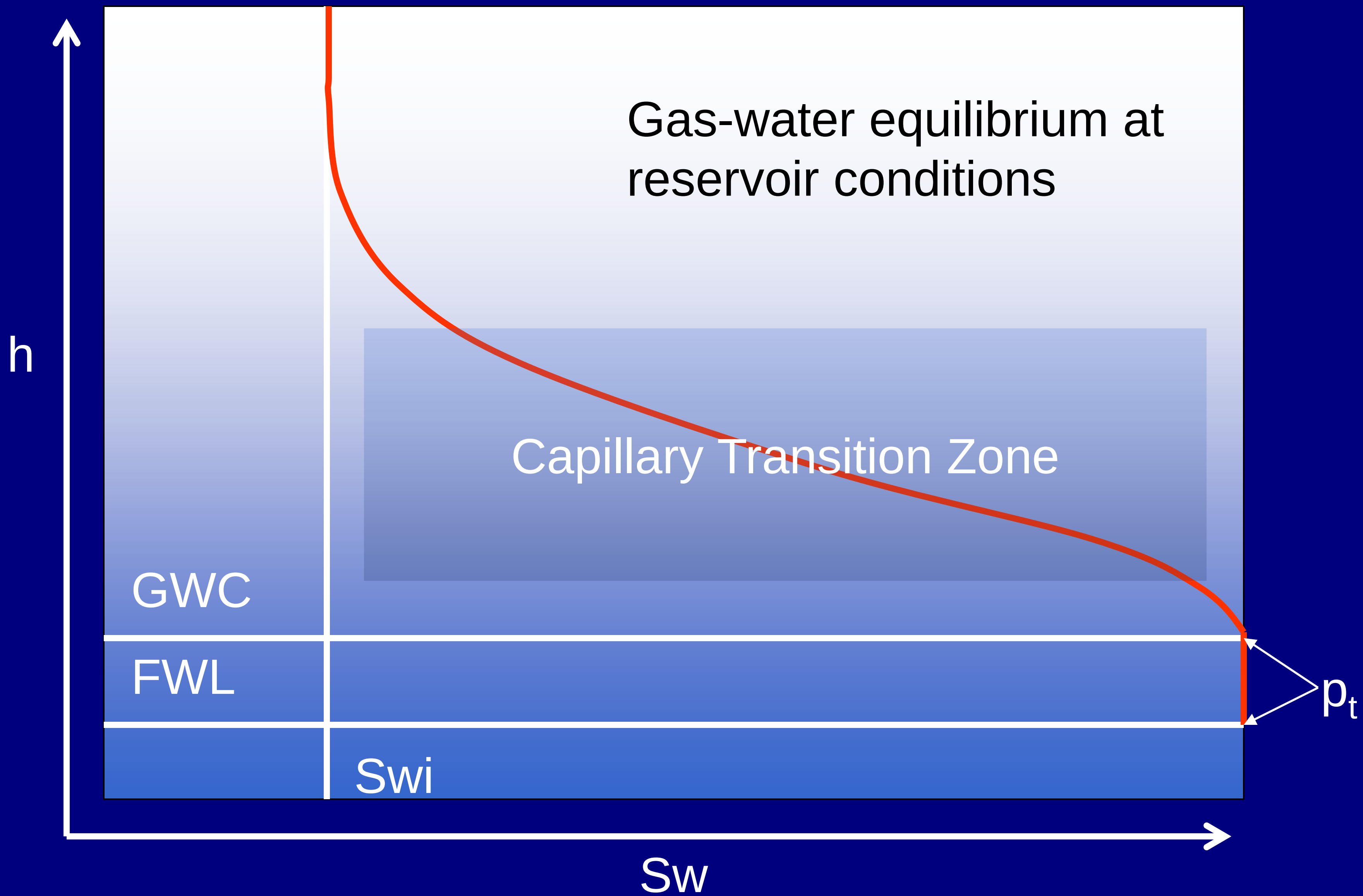
Second Definition Applicability

- Eq. [2] can be directly applied to reservoir characterization
  - The variables can be easily quantified
  - The height is specially significant for the estimation of in-place hydrocarbon

But…

- It is only valid at equilibrium conditions!

Using Second Definition …

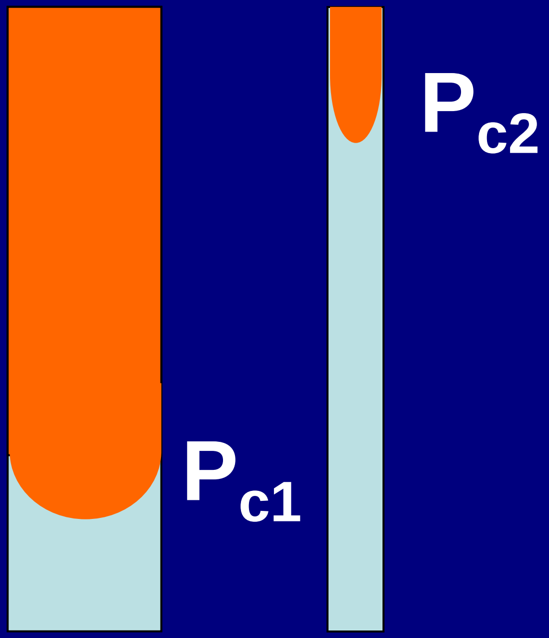


Third Definition

- $P_c = 2 \,.\, \sigma \,.\, \cos(\theta_c) / r$ [3]

  – Where

    - P_c = Capillary pressure
    - σ = Interfacial tension
    - θ_c = Contact angle
    - r = Capillary radius



- This is the "microscopic" definition of capillary pressure

Third Definition Applicability

- Restricted by our ability to define "r", "σ" and "θ"
- Allows Rock Type characterization
  - Pore size distribution (Hg injection)
- Explains and quantifies capillary forces
  - One capillary pressure for each pore geometry
  - Low permeability means high threshold pressures

Outline

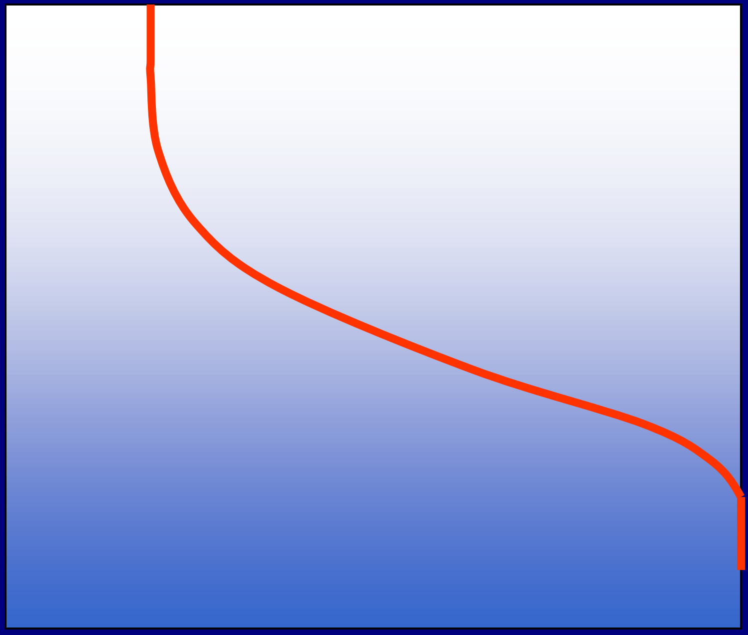
- Characteristics of Tight Reservoirs
- Objectives
- Capillary Pressure Definitions
- A Fundamental Question
- Analysis of a Physical Model
- Conclusions

Fundamental Question

- Can Eq. [2] be applied to Tight Reservoirs?

Or… in other words:

- Do "geologic time intervals" always guarantee the hydrostatic equilibrium?



Answer

- Usually affirmative in normally pressurized traps
  - Reservoir pressures are at equilibrium with superficial water sources

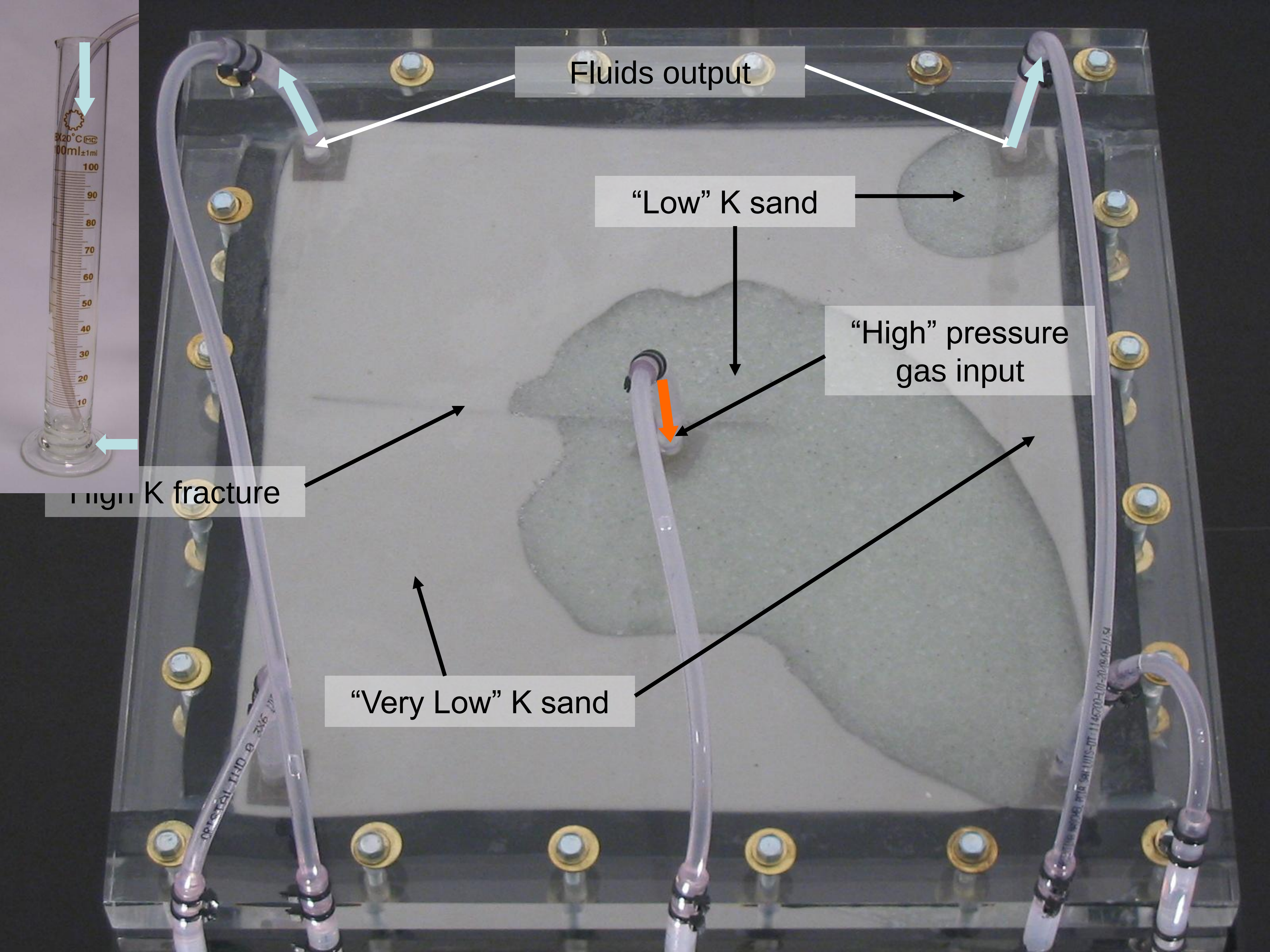
- Unknown in over-pressurized or sub-pressurized systems
  - “Over” and “Sub” prefixes mean that systems are not at the expected equilibrium conditions

Outline

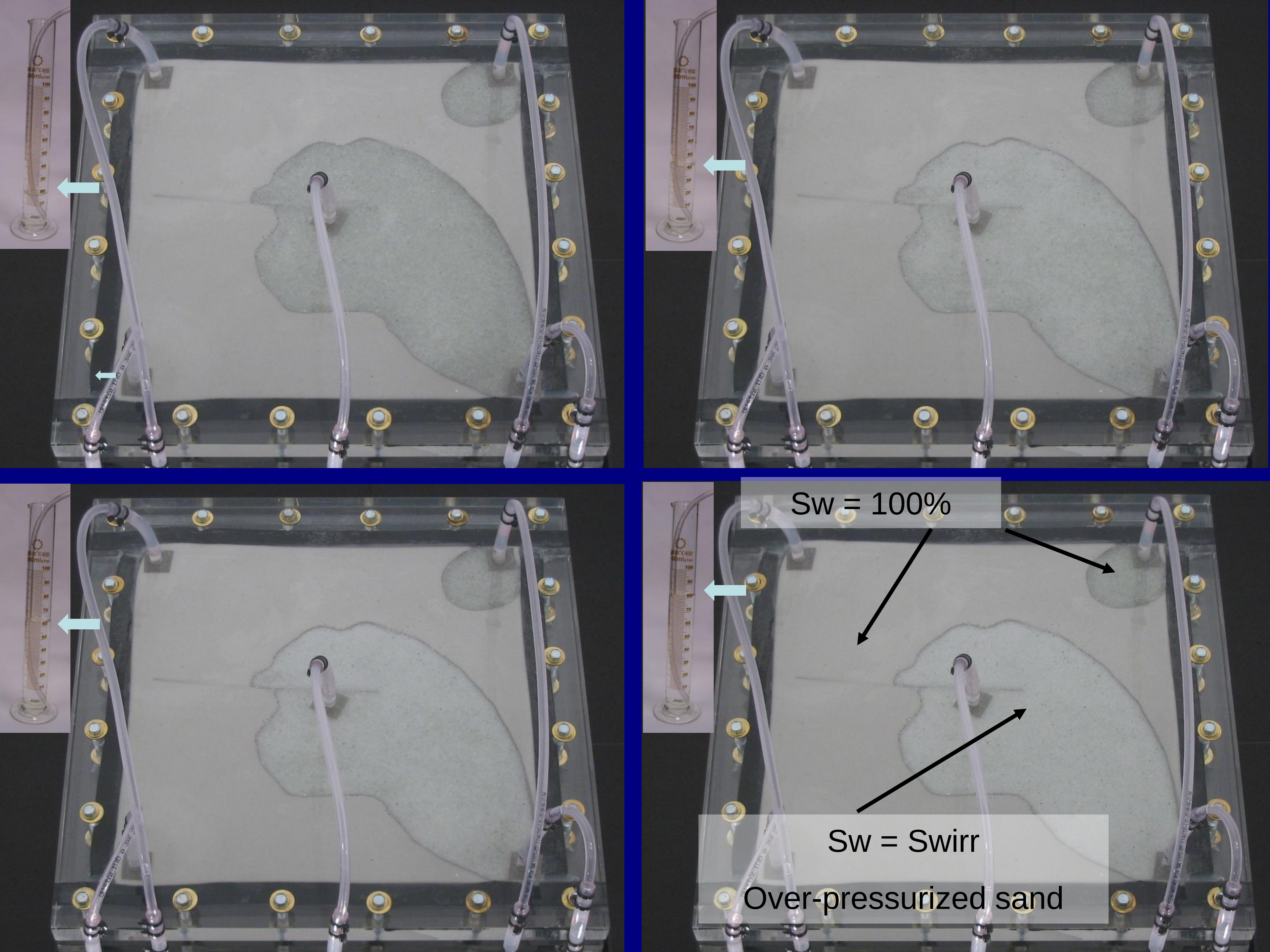
- Characteristics of Tight Reservoirs
- Objectives
- Capillary Pressure Definitions
- A Fundamental Question
- Analysis of a Physical Model
- Conclusions

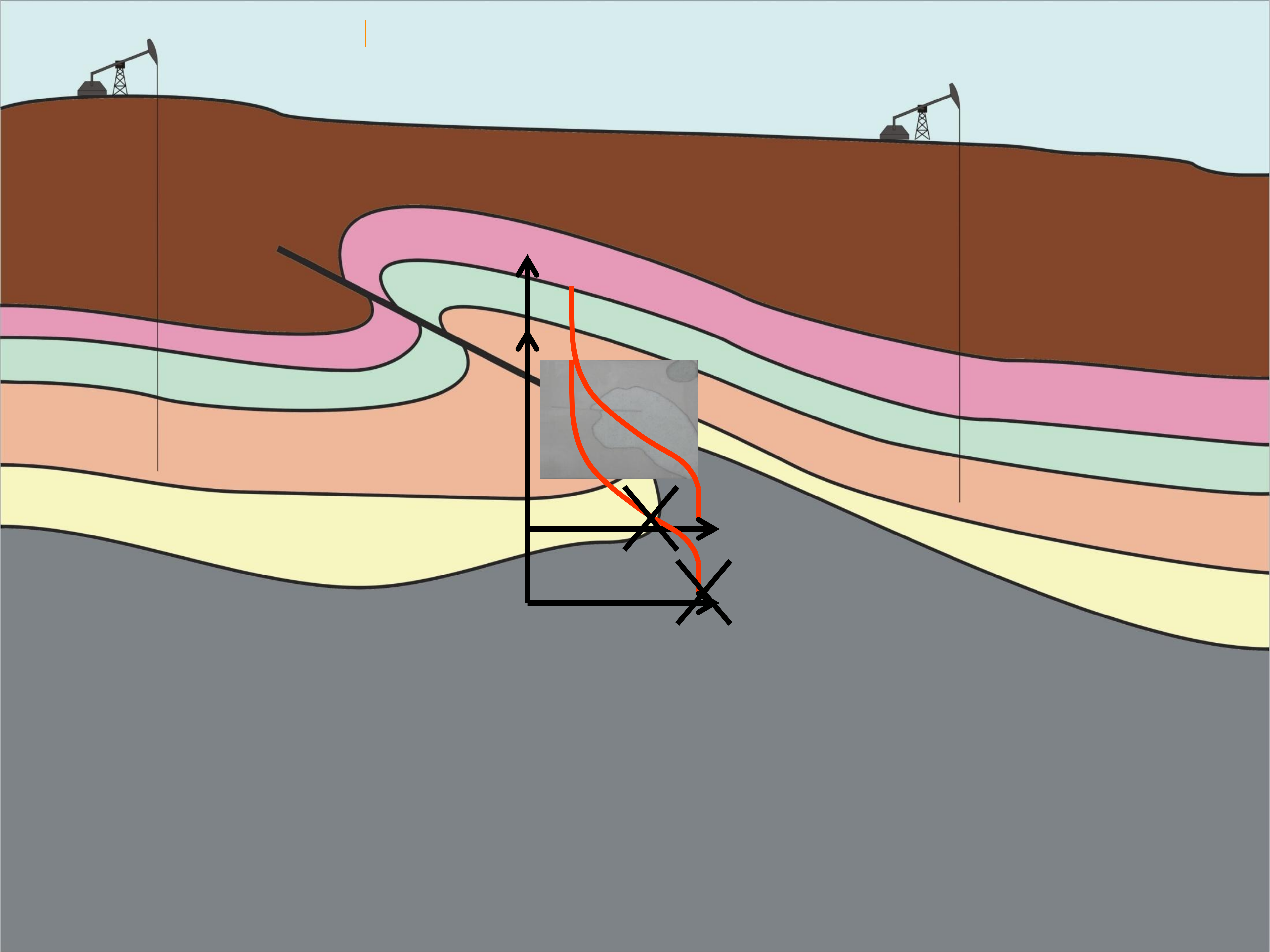
Physical Model Description

- Visual lab-scale model
- Heterogeneous
  - Just two “Rock Types”
    - “Low” permeability
    - “Very low” permeability
- Two “low” K sand bodies surrounded by “very low” K sand
- Threshold pressures much higher than hydrostatic columns inside the model
- External source of gas pressure



Fluids output
“Low” K sand
“High” pressure gas input
K fracture
“Very Low” K sand


Sw = 100%
Sw = Swirr
Over-pressurized sand



This Model Explains

- Over-pressurization (Eq. [1])
- Low water saturation (Eq. [3])
- Absence of capillary transition zone
- Isolated reservoirs
- Problems in FWL determination
- Anomalous pressure gradients
- Matrix behavior in fractured reservoirs
- Water producing levels near tight gas reservoirs

Outline

- Characteristics of Tight Reservoirs
- Objectives
- Capillary Pressure Definitions
- A Fundamental Question
- Analysis of a Physical Model
- Conclusions

Conclusions (I)

- Tight gas reservoirs could be in non-hydrostatic equilibrium conditions
- Routine lab capillary pressure tests should be used for Rock type characterization rather than for Sw calculations
  - No hydrostatic equilibrium model must be assumed
- Sw trends must be estimated from logs
- Sw representative values must be measured on preserved cores
  - Lab measurements must honor reservoir conditions

Conclusions (II)

- The location of fluids contacts are not determined by equilibrated fluids columns
  - The geometry of the accumulation is defined by Rock Types distribution

- No reserves must be necessarily expected from some “still to be detected” capillary transition zone

- The word “unconventional”, when talking about Tight Gas Reservoirs means that non-equilibrium systems are outside our usual practice

AAPG Latin America & Caribbean Region

ARGENTINA 2016
Geosciences Technology Workshop
Co-hosted by the Argentine Association of Petroleum Geologists and Geophysicists

Abnormal Pressures and Water Saturations in Tight Gas Scenarios

THANK YOU !!

Marcelo A Crotti - Inlab S.A.