

Pressures, Seals and Traps*

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Search and Discovery Article #42356 (2019)**

Posted February 25, 2019

*Adapted from oral presentation given at AAPG Middle East Region, Second EAGE/AAPG Hydrocarbon Seals of the Middle East Workshop, Abu Dhabi, UAE, April 16-19, 2018

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Abstract

Pressure, seals and traps are the basis for the Petroleum System to work efficiently. The compaction of sediments is related to fluid expulsion, mainly water, but also hydrocarbons, i.e. oil, gas, and mineral in solutions. Sediments loose mass and volume during the compaction and the diagenesis process, through a reduction of porosity. Water (mostly) is expelled and finds its way towards the surface. Most of the fluid loss occurs during the first 2000 m of burial. Pressure is defined as the ratio between a force and an area. The analyses of pressure through tests are fundamental for the petroleum geologist. Solids transmit forces and fluids transmit pressures, and rocks can be deformed, and when tight have no measurable pressure.

Pressure is normal when hydrostatic, and abnormal when overpressure is developed in undrained systems. Sealing of hydrocarbons is related to impermeable rocks and ruled mainly by two processes: capacity and integrity. The capacity of a seal is linked to its entry pressure and wettability, the more of this the more the hydrocarbon column can be. The integrity of a seal is related to its resistance to hydraulic fracturing, and conversely the closer the pressure is to the minimum stress the weaker is the sealing and the hydrocarbon column. There is another but much more marginal phenomenon - the gas molecular diffusion, which occurs longer over the geological time scale. Hydrocarbon trapping is the result of the contrast of a reservoir having a low entry pressure and a seal having a high entry pressure. If there is an important overpressure or if the hydrocarbon column is high, then the pressure can be close to the hydraulic fracture point of the seal and there is possible leakage.

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Jean-Jacques Biteau

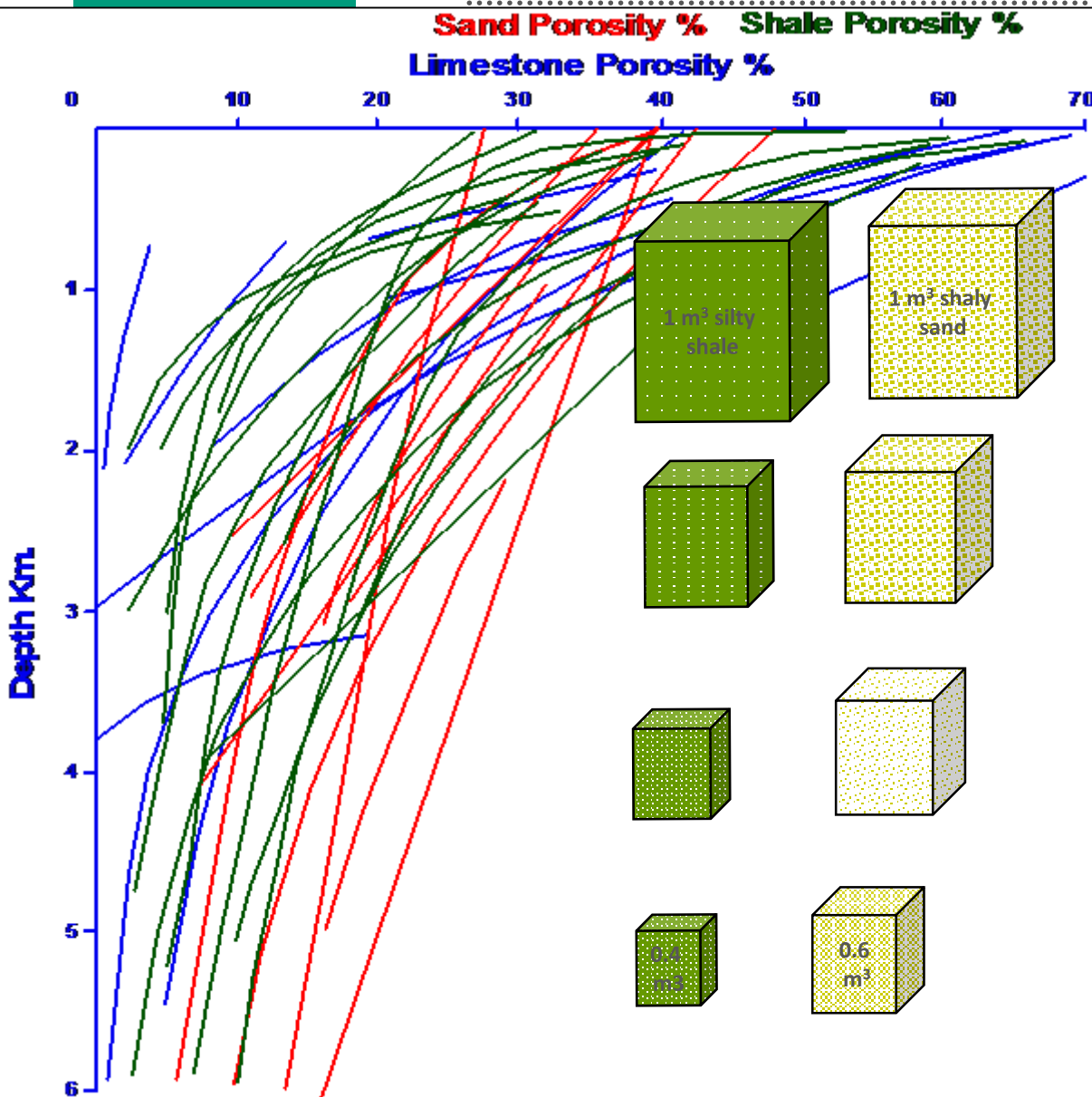
EAGE President 2017-2018

KEYNOTE SPEECH

**PRESSURES
SEALS & TRAPS**

EAGE ABU DHABI, JJ BITEAU, APRIL 17th 2018

- **Pressure Definition**
- **Water Head Definition**
- **Trap, Reservoir and Seal Continuity**
- **Overpressures (Consequences and Causes)**
- **Main Sealing Mechanisms**



- Sediments lose mass and volume during the compaction and diagenesis process, through a reduction of porosity

- Water (mostly) is expelled and finds its way towards surface

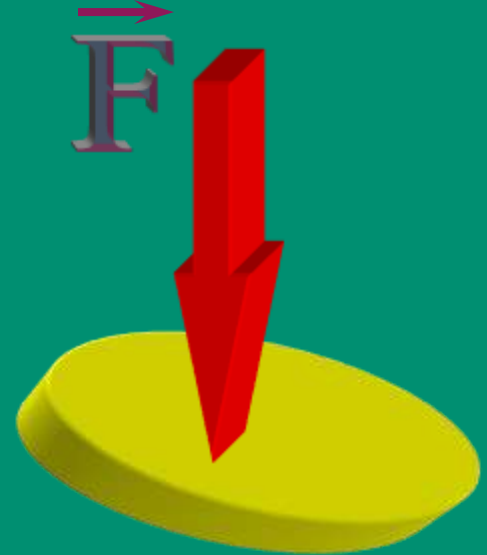
- Most of the fluid loss occurs during the first 2000m of burial

PRESSURE: Definition and Units

$$\text{PRESSURE} = \frac{\text{FORCE}}{\text{AREA}}$$

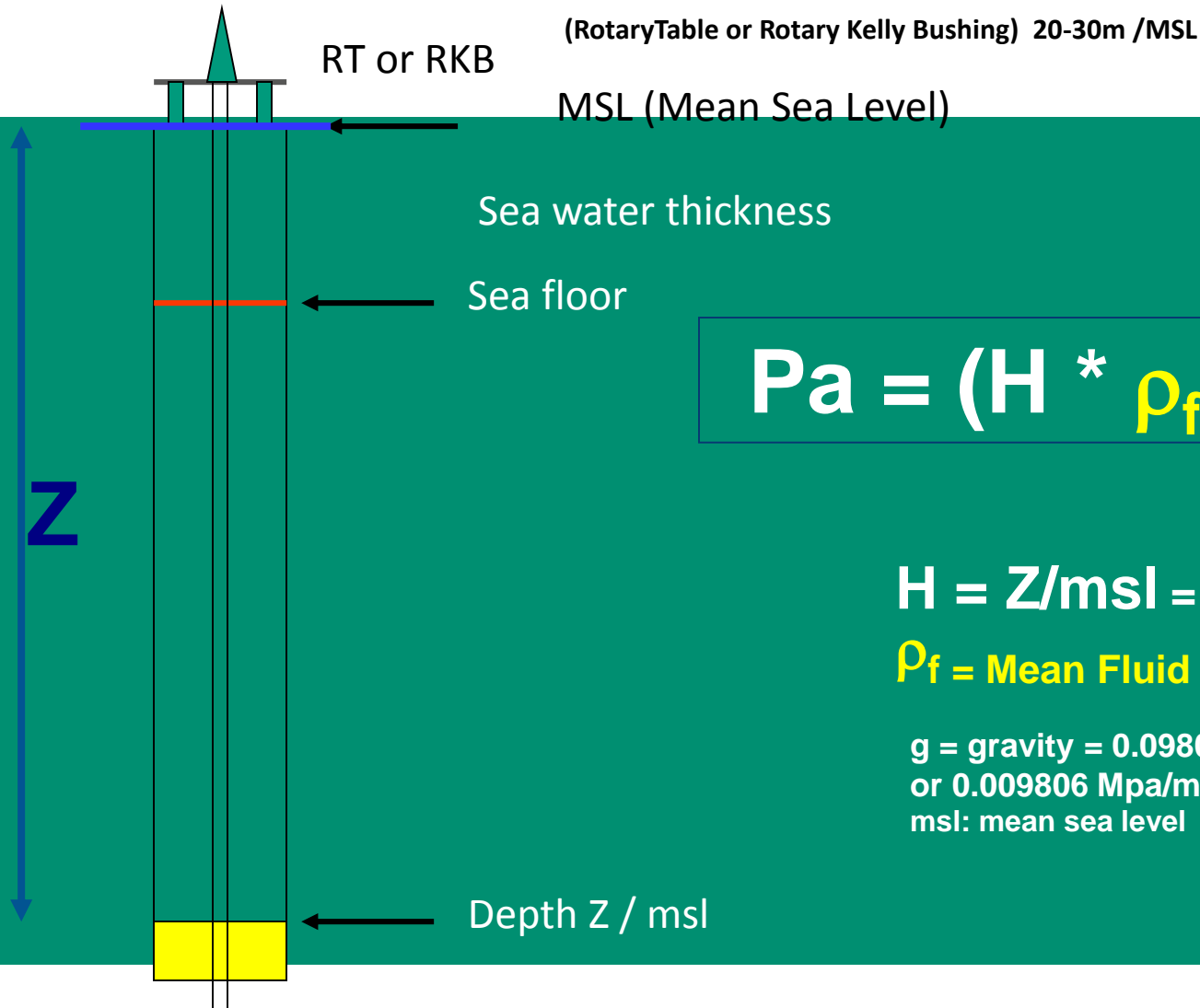
S.I. Unit : N/m^2 (Pa)

Field units : bar or MPa, kgf /cm²
psi (pound per square inch)



*Solids transmit forces
and fluids transmit pressures
Then rocks can be deformed
and when tight have
no measurable pressure*

Hydrostatic Pressure Calculation



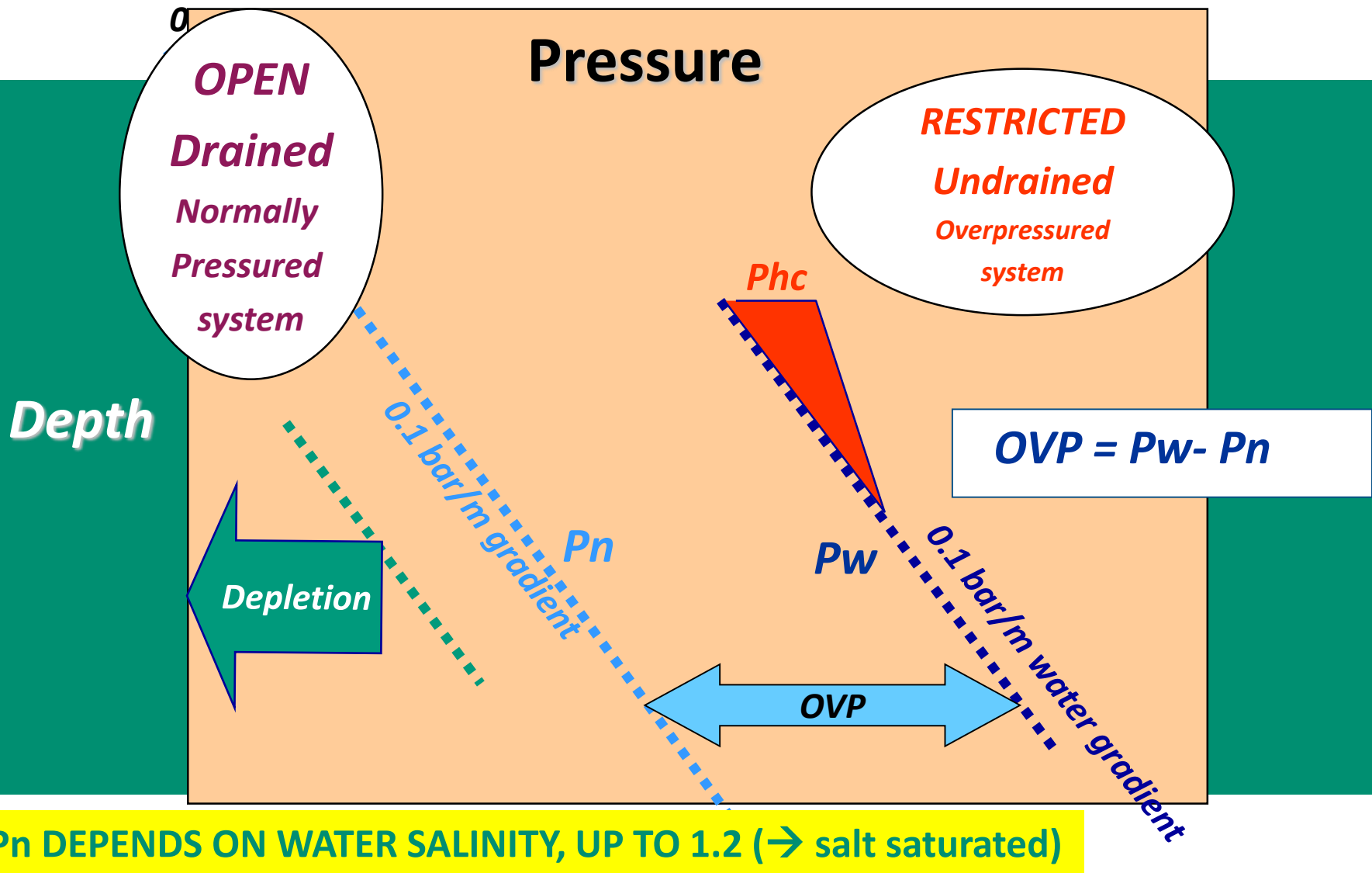
$$P_a = (H * \rho_f * g) + P_o$$

$$H = Z/\text{msl} = Z/\text{RT} - \text{RT}$$

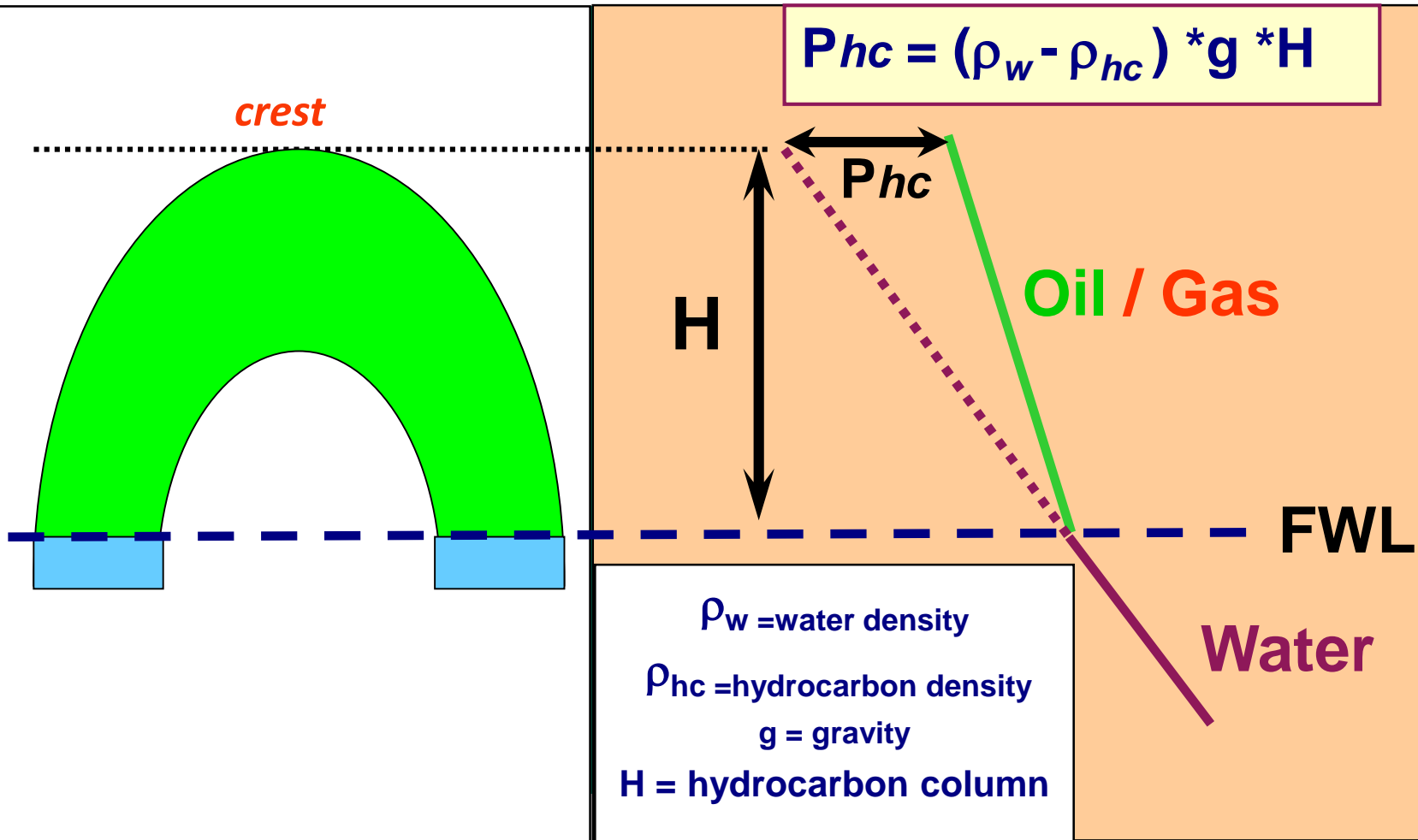
ρ_f = Mean Fluid density value

g = gravity = 0.09806 bar/m
or 0.009806 Mpa/m or 9.806 m/s²
msl: mean sea level

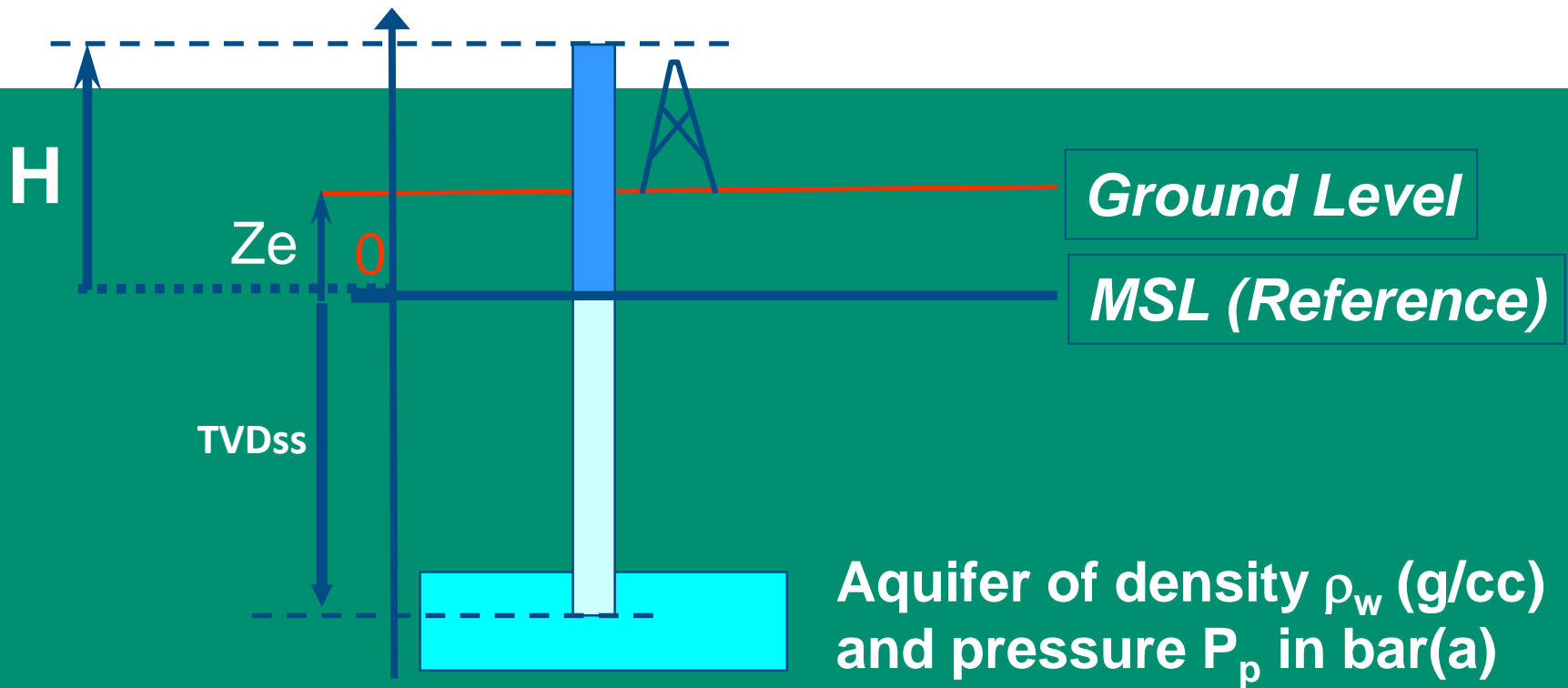
Subnormal / Abnormal Pressure Regimes in Reservoirs



Buoyancy Quantitative Assessment



Notion of Water Head

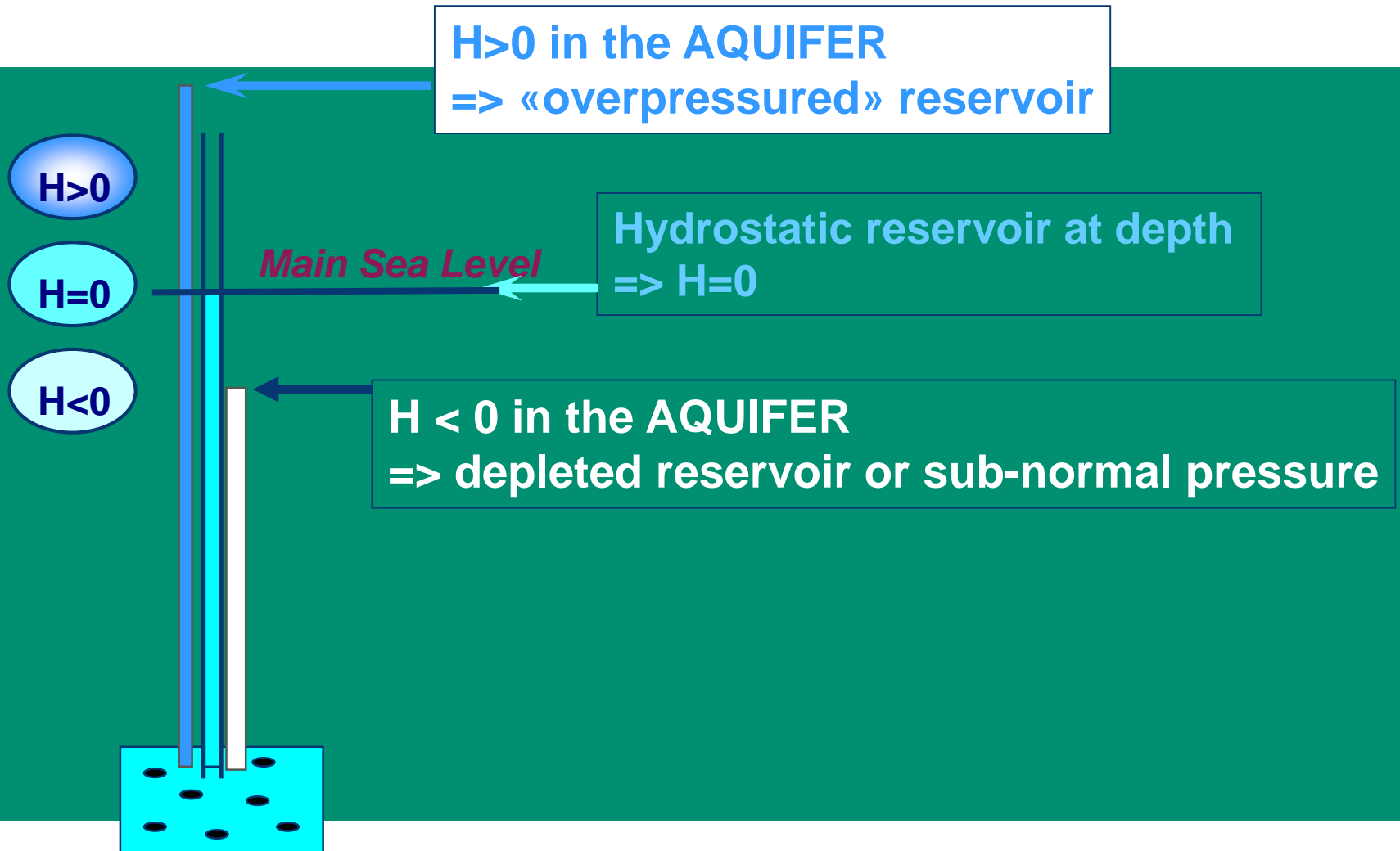


H = (true) potentiometric head of the aquifer = WATER HEAD
= Equivalent column height of water above sea level

Question:

What is the link between water head and overpressure ?

Water Head Possible Variations



Water head (pseudo potentiometric head)

$$H (m) = \frac{P (MPa) * 101.97162}{\rho_w} - \text{TVD ss (m)}$$

with ρ_w water density = 1

Water head (piezometric head = true pot. head)

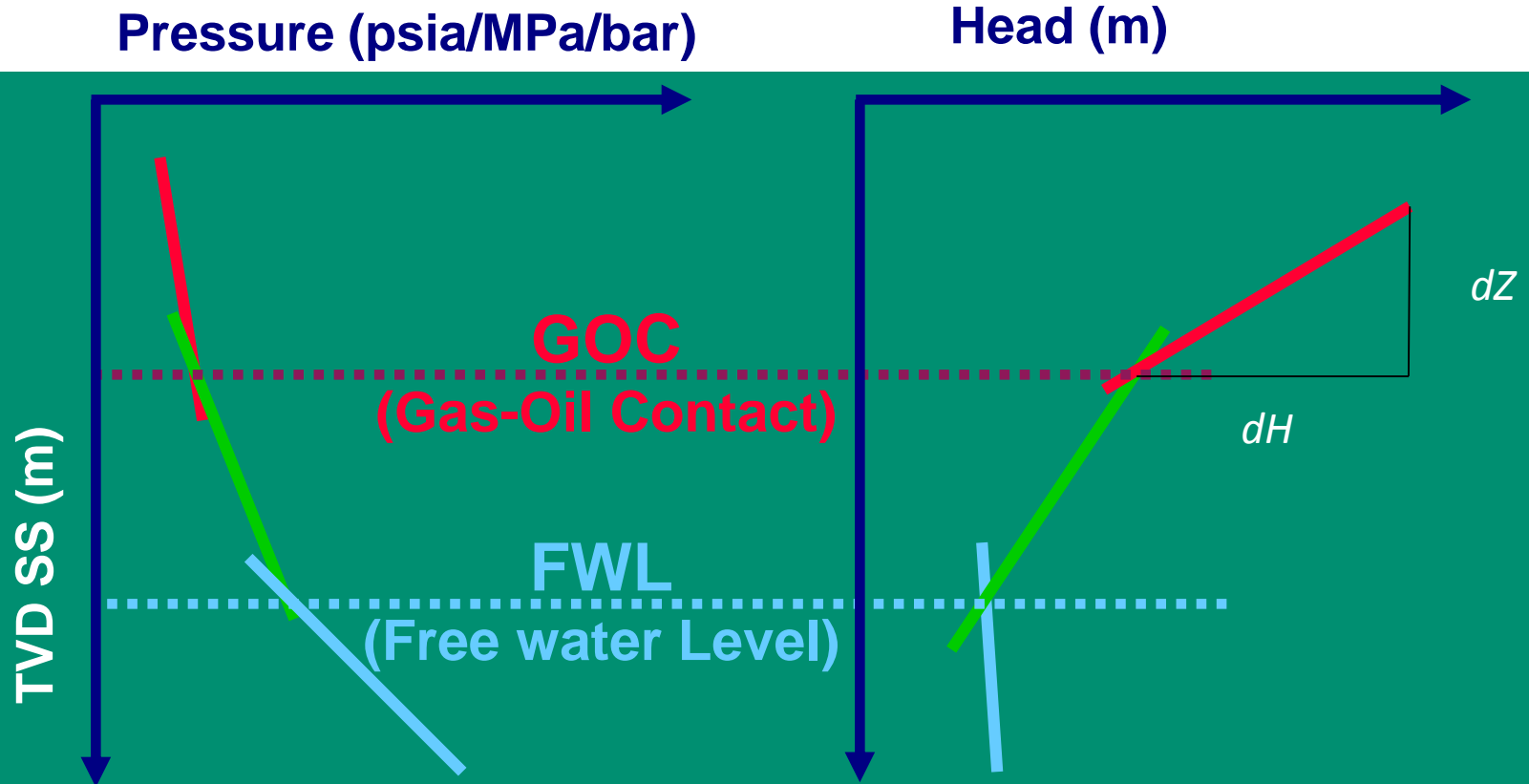
$$H (m) = \frac{P (MPa) * 101.97162}{\rho_w (g/cc)} - \text{TVD ss (m)}$$

ρ_w = formation water density

if ρ_{mean} ==> potentiometric head

$$\begin{aligned} \text{rhof (g/cc)} &= [\text{bar/m}] \times 10.1972 \\ &= [\text{kgf/cm}^2.\text{m}] \times 10 \end{aligned}$$

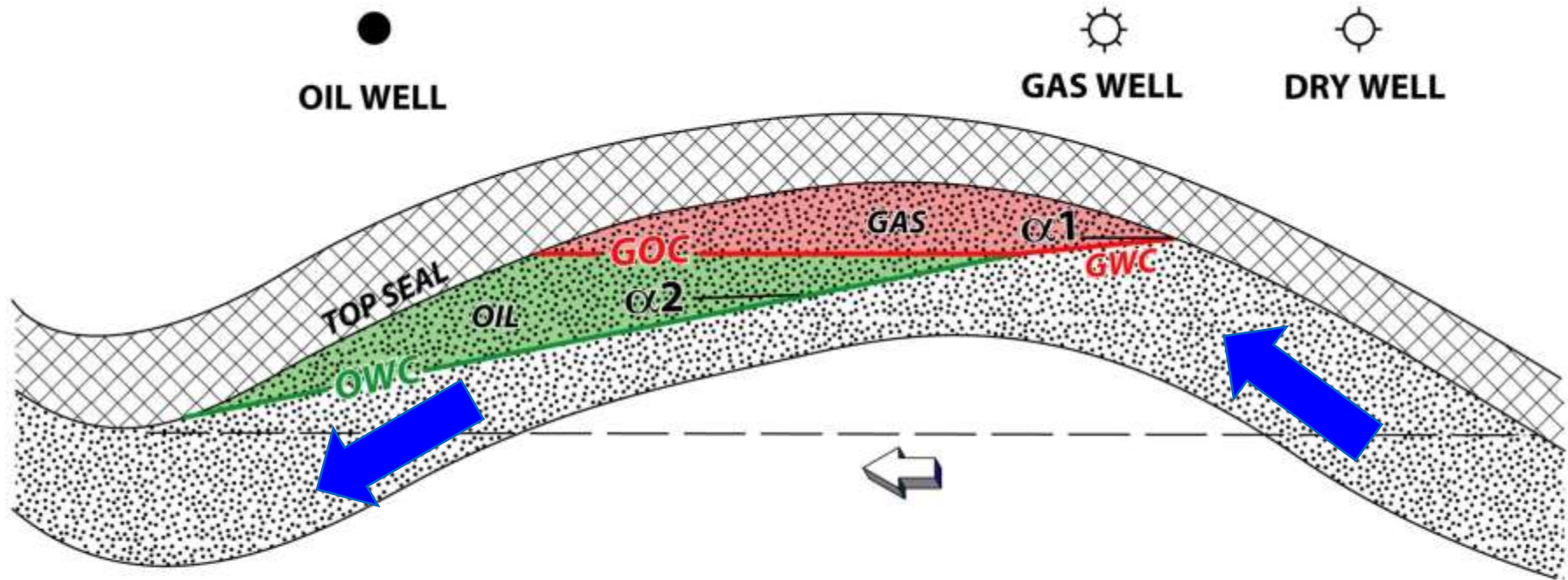
Pressures Vs. Water Head



$$HC \text{ density: } D_{hc} = D_w * [1 - (dH/dZ)]$$

TILTED CONTACTS RELATED TO HYDRODYNAMISM

SEE MASCATE 2016 WS N°1 PRESENTATION



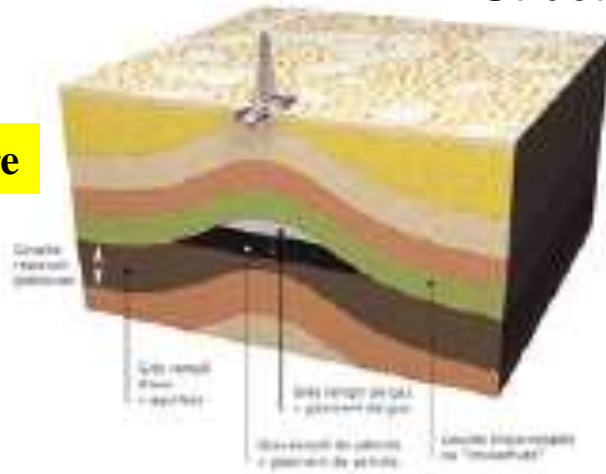
NOTE THE CHANGE OF TILT ANGLE α_1 vs α_2 FROM GWC TO OWC.
THIS IS DUE TO BUOYANCY DIFFERENCES
(GAS IS FOUR TIMES MORE BUOYANT THAN OIL)

Gas
Oil
Hydrocarbon
Sealing interval

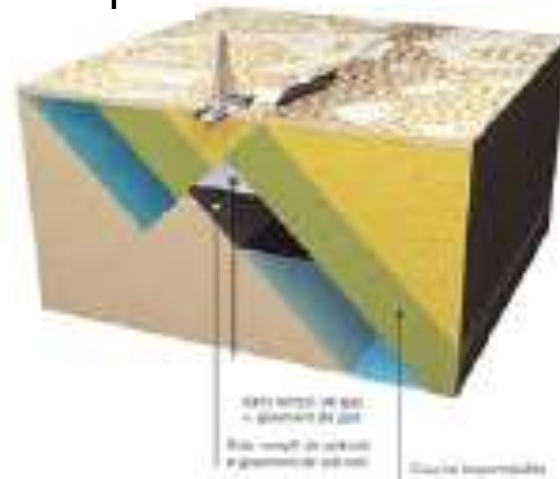
A trap is composed of a container : the reservoir
and of a seal : the cap rock.

Structural Traps

4-ways Closure

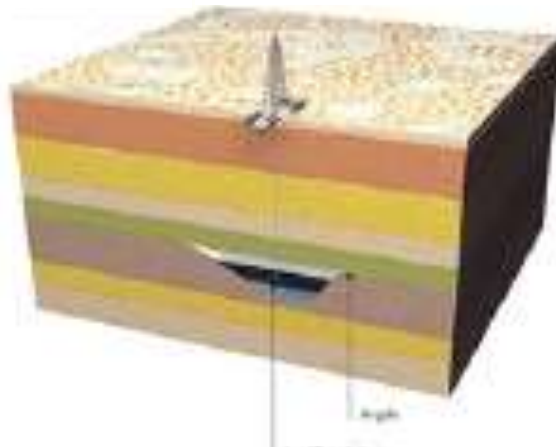


Fault Trap

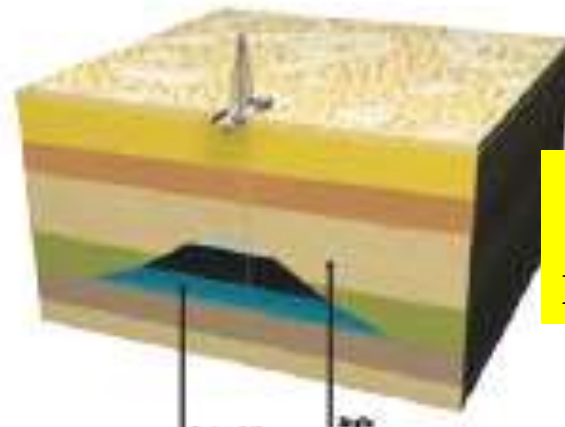


Traps with stratigraphic components

Channel Fill



Reef
Isolated P.F.
Morphological Trap

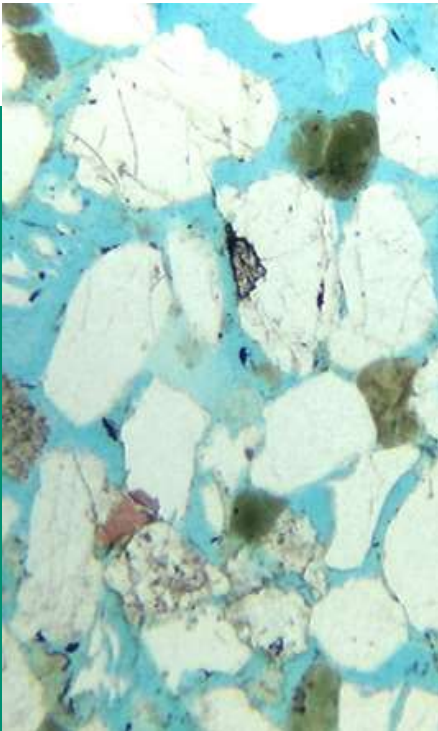


The reservoir is porous and permeable.

The cap seal is theoretically impermeable but can be slightly permeable and leaking.

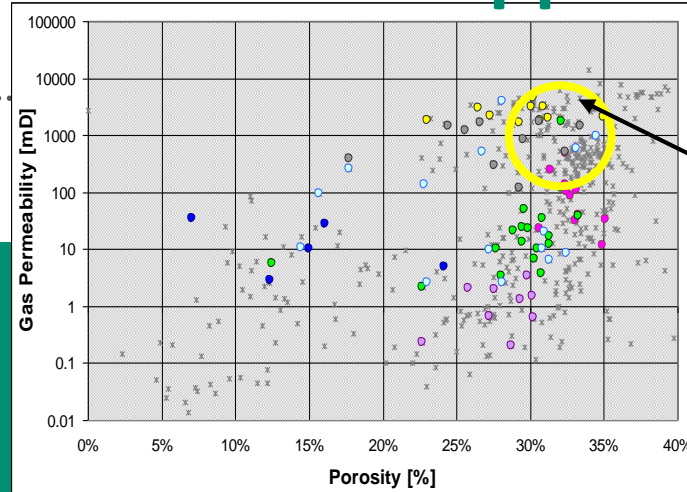
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RESERVOIR-SEAL: Apparent Dichotomy



Clean sand and
large grain size

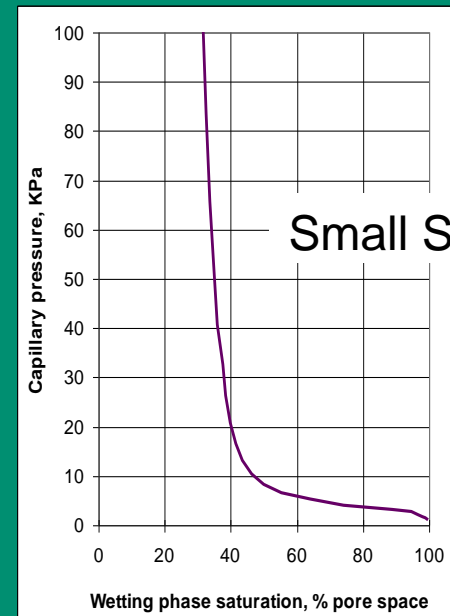
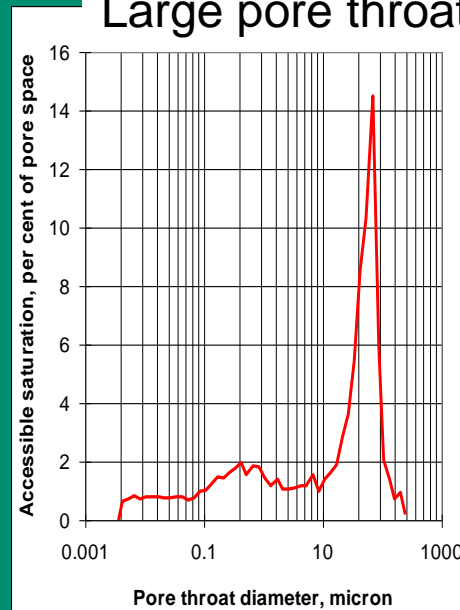
Small amount of
micro porosity



RESERVOIR

High Φ
Very high K

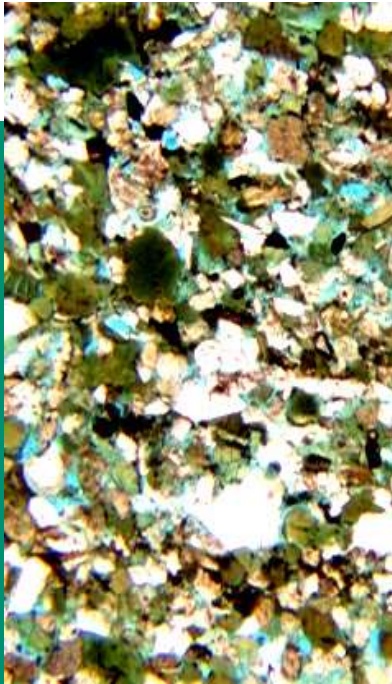
Large pore throat size



Small Swi

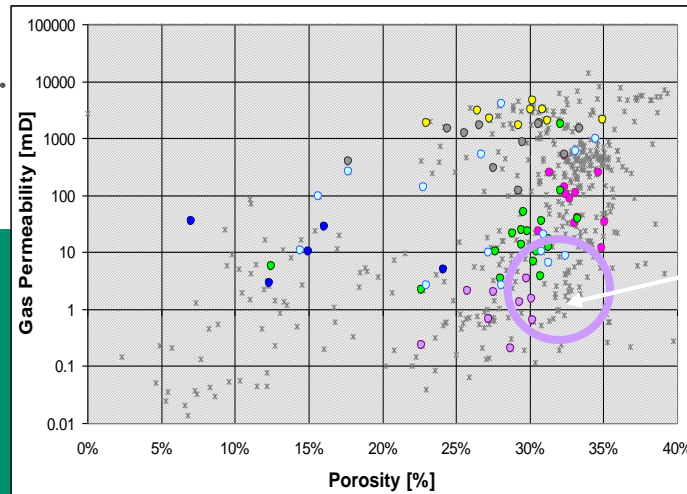
RESERVOIR-SEAL: Apparent Dichotomy

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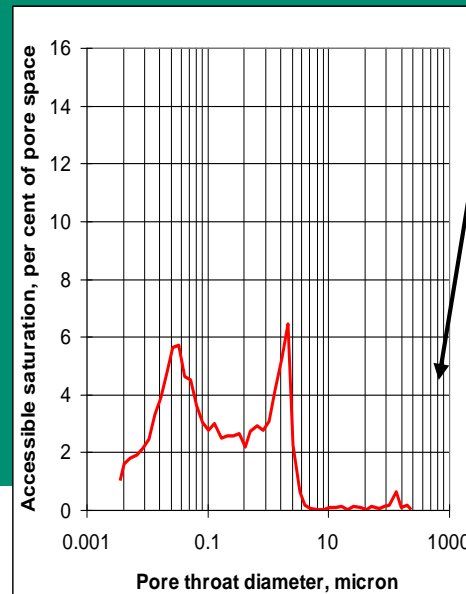


Sand with a large proportion of clay and small grain size

Large amount of micro porosity



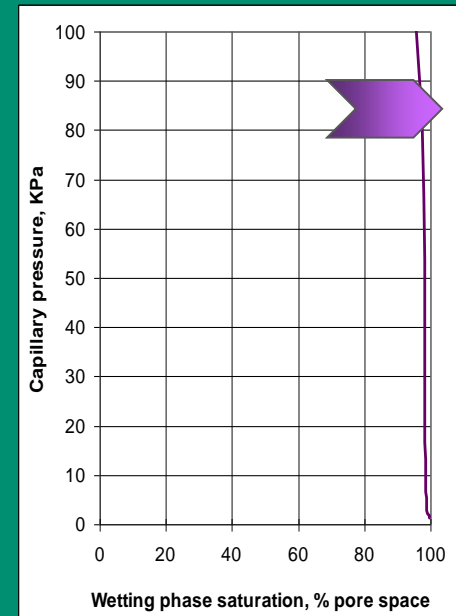
Very small pore throat size



SEAL

High Φ
Very low K

100 % water saturated
Never drained by oil !



Well Correlations : a Basis for Seal identification The need for a regional approach

Well C

Well Gi

Well G2 ST

Well G1

Well M

Well Ca

MM14.2cs

OL24.6cs

OL28.0cs

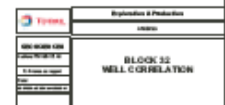
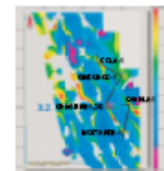
OL29.0cs

OL29.5cs

OL30.6cs?

OL33.7sb

OL33.7sb



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W.Africa Deep Offshore wells Main Seals and Pressure Data

Onshore

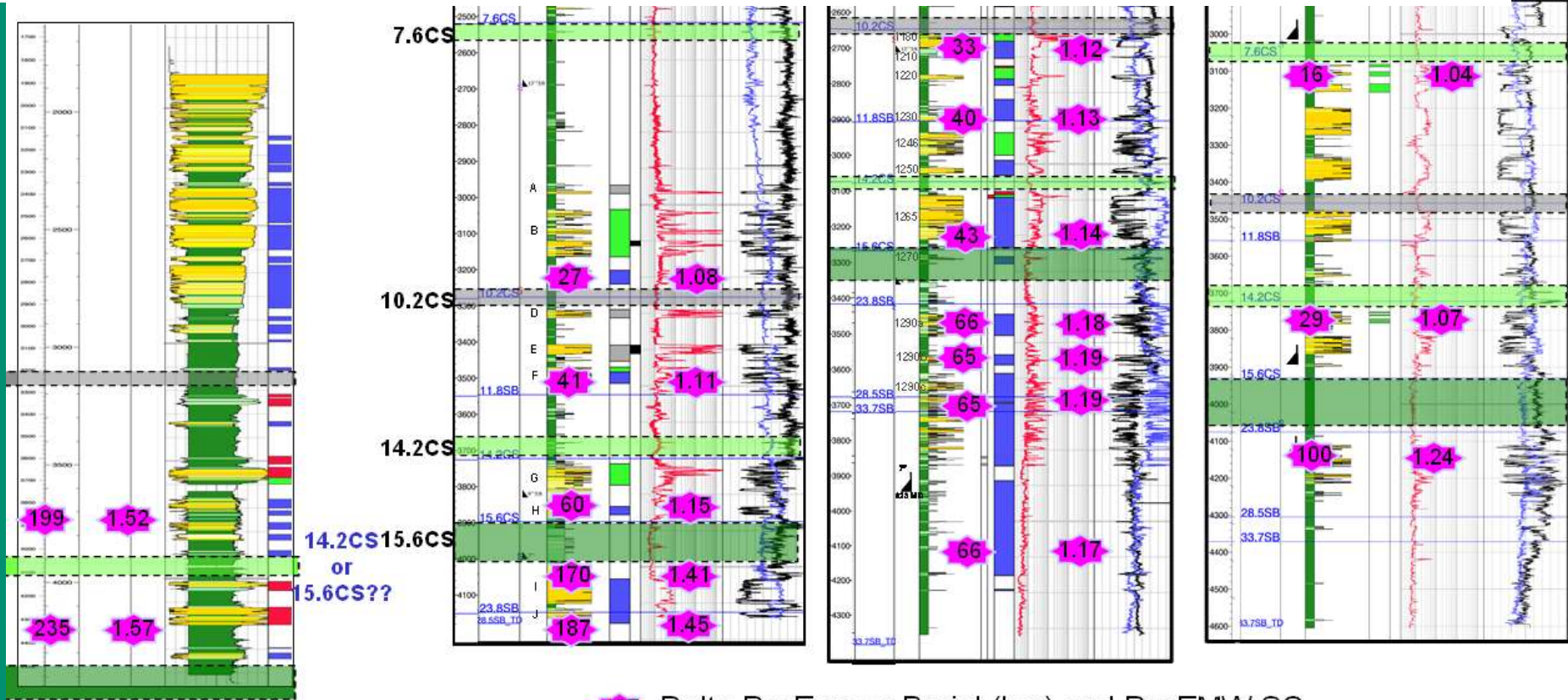
Deep Offshore

Shelf Well

WELL A

WELL E

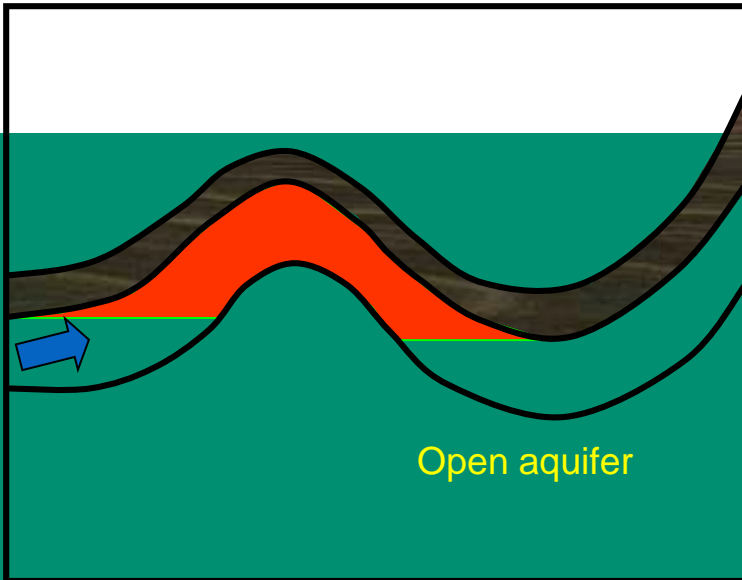
WELL O



187 Delta Pw Excess Burial (bar) and Pw EMW SG

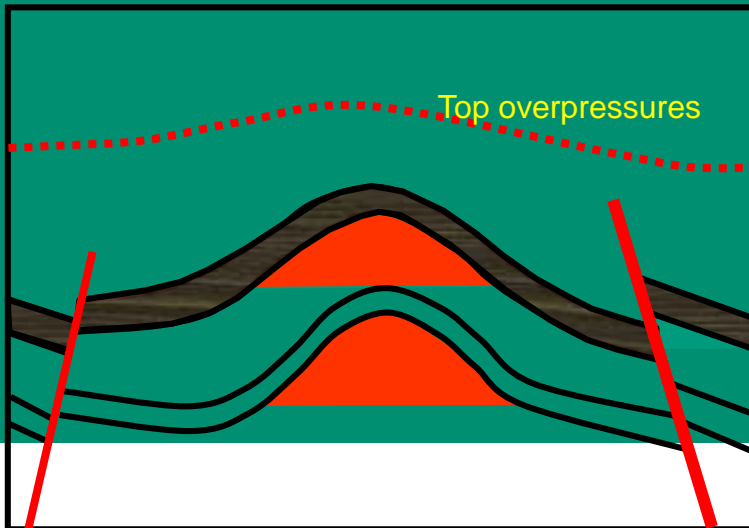
NEED FOR AN INTEGRATED APPROACH SEQ STRAT and
PRESSURE = BEST TOOL FOR THE GEOLOGIST

“Open” vs. “Restricted” Systems



Open system

- = Hydrostatic
- = Connected aquifers
- = Fair permeability
- = Good drainage
- = Dynamic system



Restricted system

- = Overpressured
- = Isolated, disconnected, aquifers
- = limited fluid flows
- = undrained systems
- = Low permeability ults
- = compartmentalization

OPERATIONAL IMPACT OF OVERPRESSURE PREDICTION



RANKING OF MAJOR OVERPRESSURE GENERATING MECHANISMS

- **Compaction Disequilibrium (Mechanical Stress)**
- **Active Organic Matter Transformation**
- **Dynamical pressure transfer**

Secondary or less frequently significant in exploration:

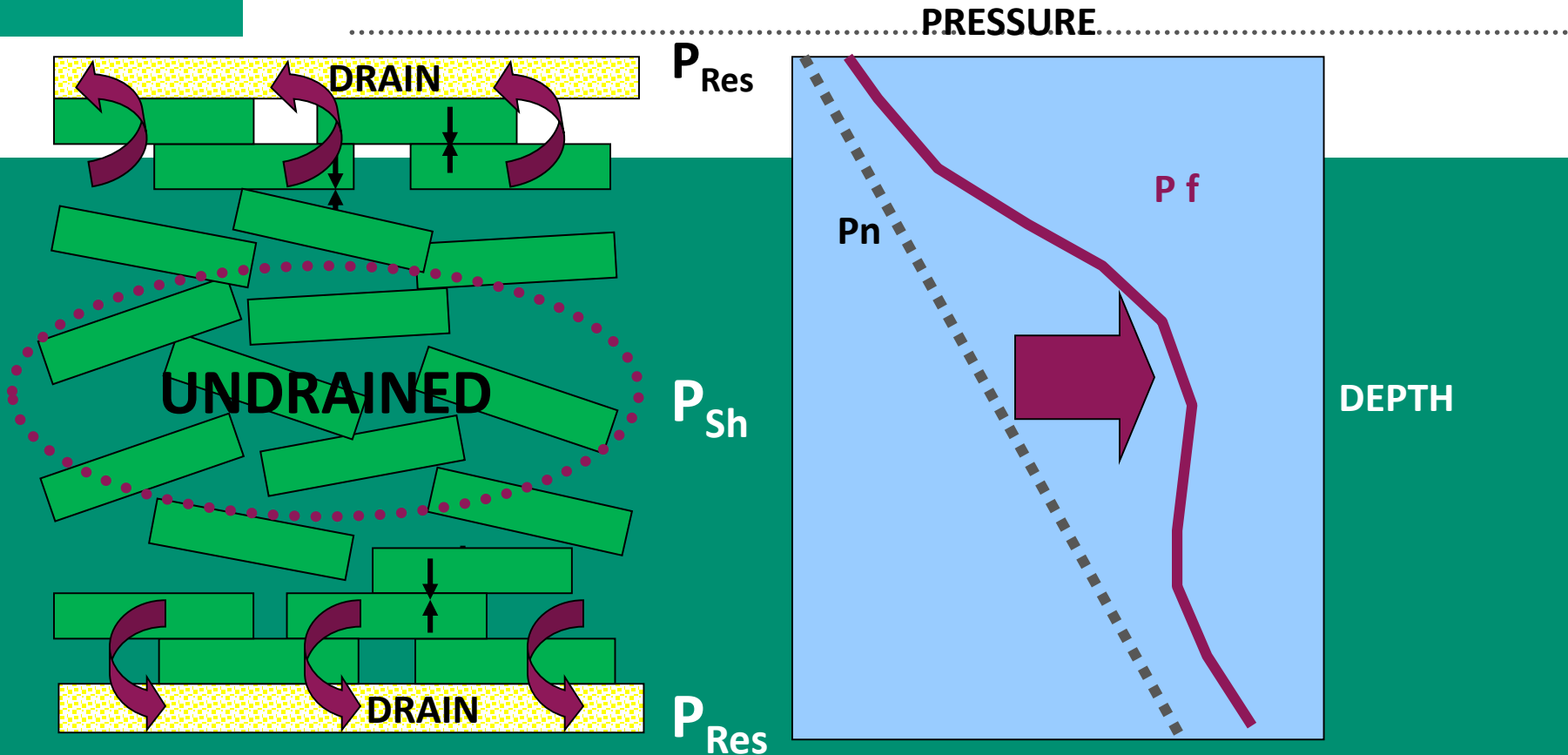
- **HC buoyancy**
- **Tectonic Uplift**
- **Lateral Tectonic Stress**

**Importance of the tectono-sedimentary context, able
or not to dissipate the overpressure**

Sand extension, sand thickness, sand connection, sand and fault permeabilities

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POORLY DRAINED CONDITIONS \Rightarrow OVERPRESSURE



Shales/clays layers become partially fluid-supported: Fluid cannot escape

- > PHI remains constant vs Z : shales become undercompacted
- > fluid supports a part of Overburden (S1) : PRESSURE is ABNORMAL

Notion of « **P Shale** » and **P Reservoir**

Sealing ***Capacity*** of a cap rock

is a function of

- its entry pressure P_e , preventing hydrocarbons to invade the capillary network
- its permeability K , (**KV and KH**) controlling the flow of hydrocarbons through the seal once the P_e is reached

Sealing ***Integrity*** of a cap rock is a function of its resistance to hydraulic fracturing (pore pressure /minimum stress S_3)

Sealing Efficiency Mechanisms

Important definitions

Pressure Seal Effect

corresponds to the differential between pressure in seal and trap
may be « vertical » hydrodynamism: $P_{sh} > P_{res}$, it re-enforces the retention efficiency

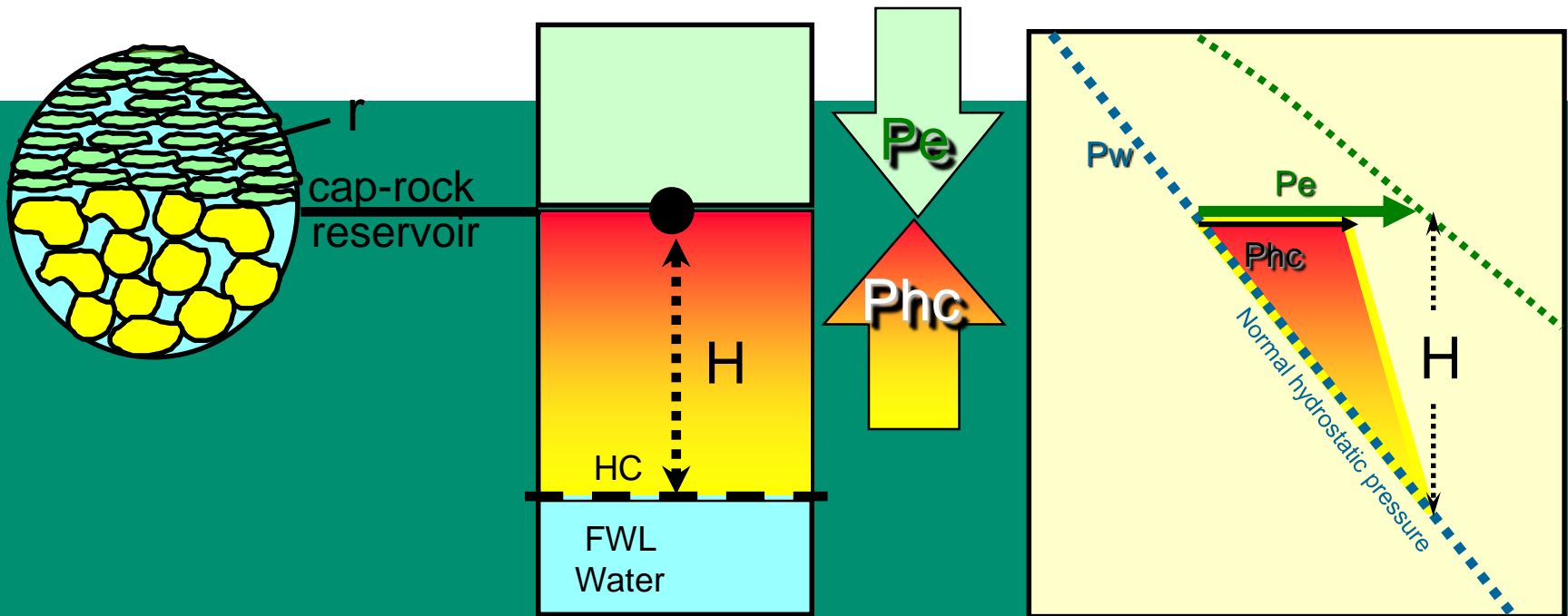
Reservoir Overpressure

corresponds to a differential pressure within a reservoir layer
may be hydrodynamism, active aquifer, water drive...

Molecular Diffusion of Gas

through a shaly cap rock is a slow but permanent process

Sealing Capacity - Capillary effect



Cap rock Capillary leakage when $P_{hc} > P_e$

P_{hc} : HC induced buoyancy effect

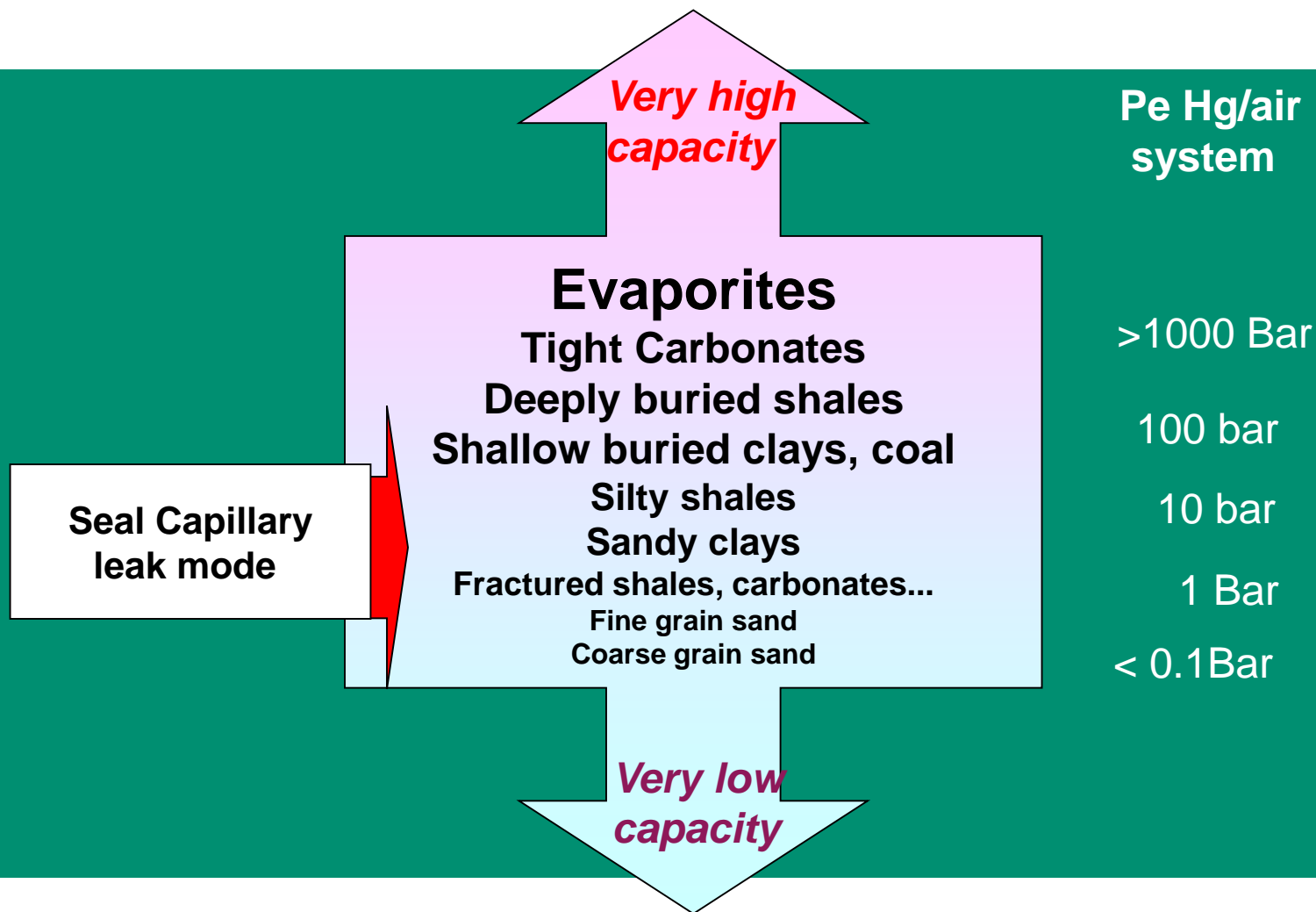
$$P_{hc} = (\rho_w - \rho_{hc}) \cdot g \cdot H$$

$>$

P_e : Capillary entry pressure

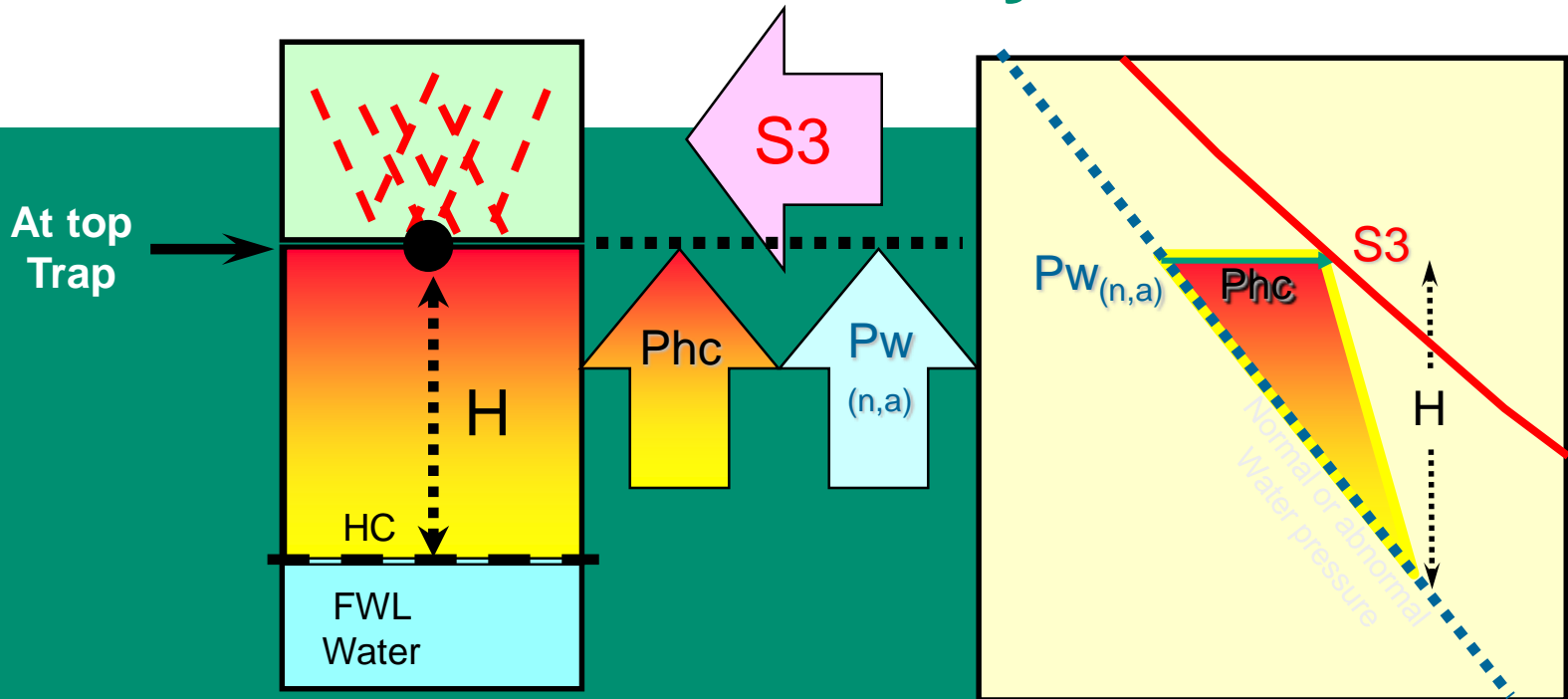
$$P_e = 2 \times \text{IFT} \times \cos\Theta / r$$

Capillary Retention - Lithofacies Ranking.



Sealing Integrity

Resistance to Hydraulic Fracturing



SEAL BREACHING LIMIT = $S3$

Cap rock hydro-mechanical leakage whenever: $P_{hc} + P_w > S3$

P_{hc}

HC induced buoyancy effect

$$= (\rho_w - \rho_{hc}) \cdot g \cdot H$$

$>$

$S3$

**Minimum
principal stress**

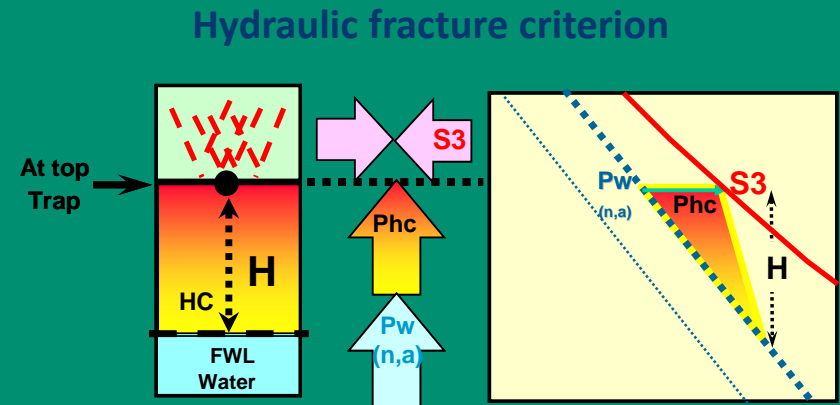
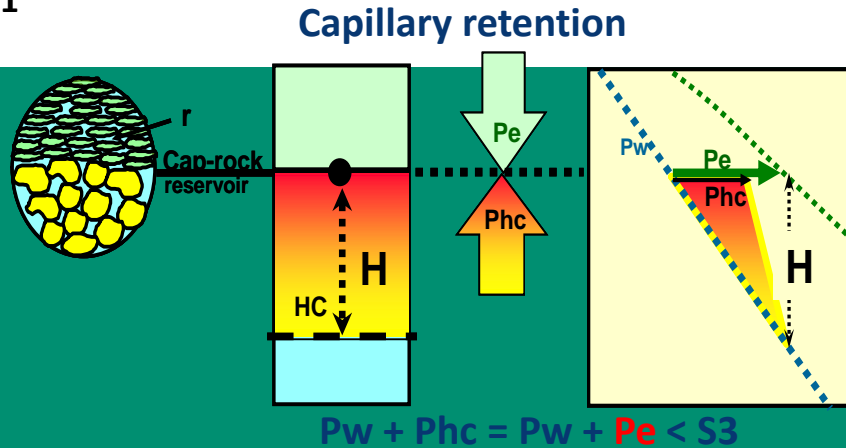
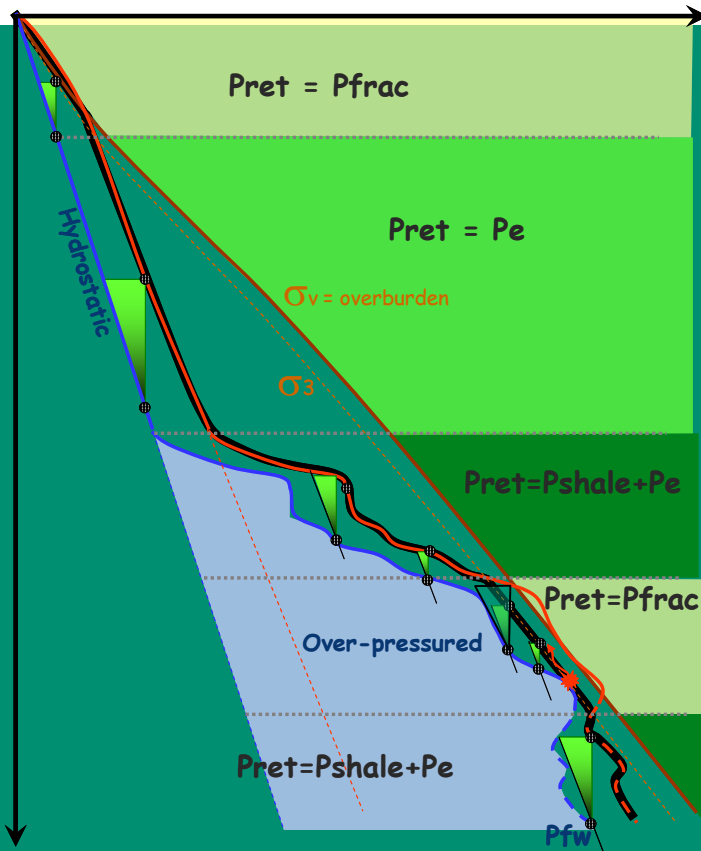
Hydrofracture leak criterion

$P_{w(n,a)}$

**Normal or Abnormal
Water pressure**

Top Seal Efficiency Criteria

Extensional geological context : $\sigma_v = \sigma_1$



P_{fw} = pore pressure water

P_{ret} = Retention pressure

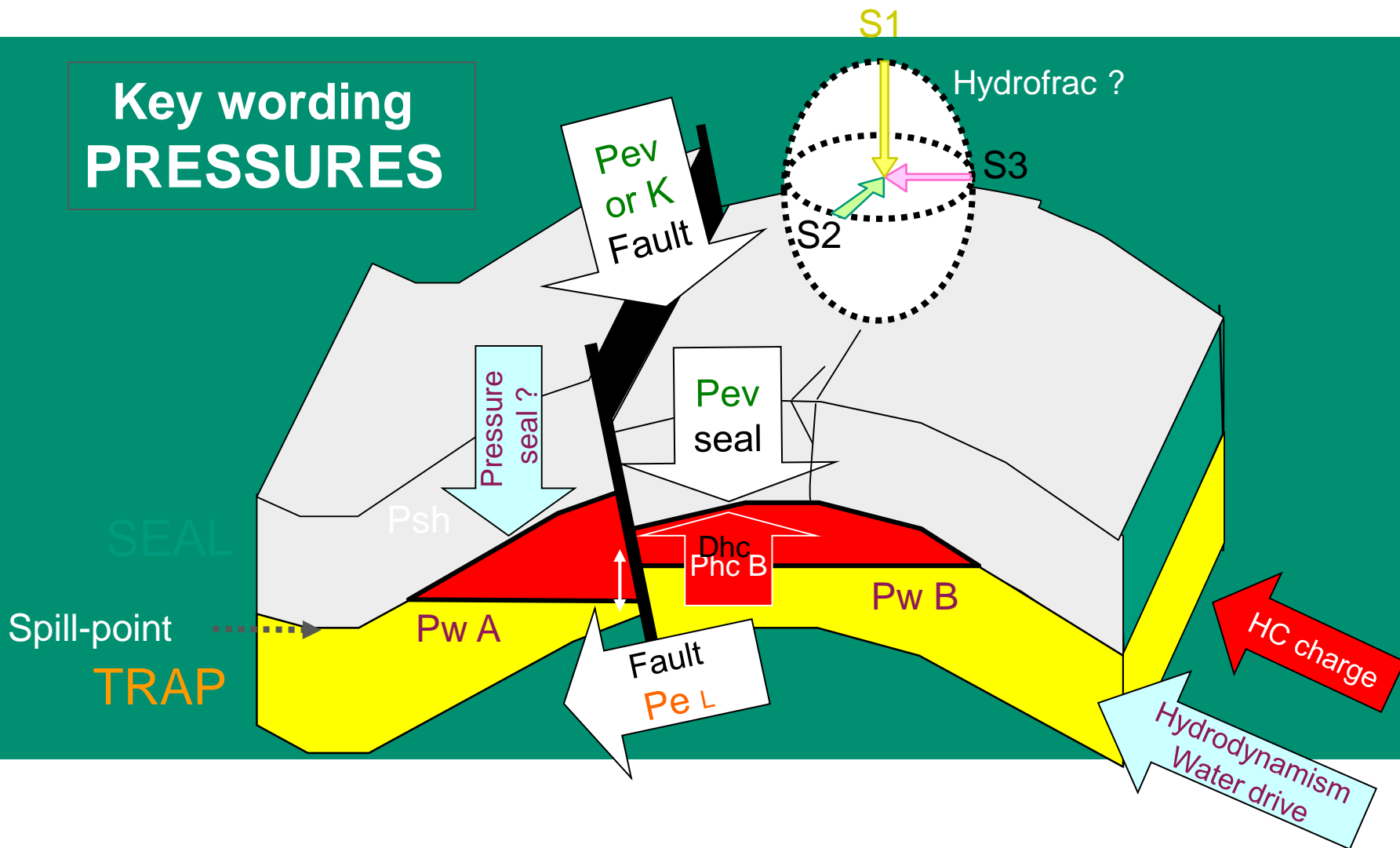
P_e = entry pressure

P_{frac} = hydraulic fracturing pressure

$$P_w + P_{hc} = S_3 < P_w + P_e$$

"SEAL and TRAPS" Key Parameters

Key wording
PRESSURES



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