Sealing - What Are We Risking?*

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Abstract

Risking of oil and gas prospects is one of the fundamental activities in Hydrocarbon Exploration, with companies adopting very similar, but often slightly different risking schemes. Seal Risk is one of the elements of these risking schemes, but the exact definition and aspects covered by Seal Risk may vary, or can even be ambiguous. Below are just a few cases which may result in differences in Seal Risk assessment:

● It can have overlap with Structure Risk when fault seal is part of the trapping configuration. In order to avoid this ambiguity, Closure Risk is proposed, which is the risk of having no closure irrespective top, base and lateral elements of its seal.

● An effective seal at time of charging does not guarantee retention of hydrocarbons post-charge. Sometimes retention is treated as a separate risk element, sometimes it is included as part of Seal Risk. It is proposed to explicitly include retention risk in the Seal Risk for consistency reasons.

● Seal effectiveness may be different for oil and gas.

For overall prospect risking, these subtleties should not matter, as long as they are (1) not overlooked (resulting in underestimation of prospect risk), or (2) not included in multiple risk elements (with the risk of "double-dipping" and hence overestimation of prospect risk).

However, in order to have a useful discussion on Seal Risk, it is essential to properly understand what actually is captured by it. In addition to above subtleties in Seal Risk definition, the continued search for hydrocarbons is challenging some of the tradition concepts. As a consequence, the established risking schemes, including the concept of Seal Risk, may be too rigid to properly describe and assess the subsurface risk profile of a prospect. Some examples of this are:

● Indications are emerging that some existing accumulations associated with recent restructuration have not equilibrated to their current structural configuration, and are transient between paleo-structure and current structure. In other words, these are accumulations “on the move”.

In both examples, it is difficult to define what Seal Risk actually is, and one should be careful to try to risk such opportunities in the straightjacket of a conventional risking scheme. Therefore, Seal Risk should be treated as one (important) element of play and prospect risking. Established risking schemes can be useful as a start, but it is up to every explorationist to describe his or her opportunity and portray the risks transparently, which may require challenging these schemes and associated dogmas, and hence the concept and definition of Seal Risk.

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Sealing – What are we Risking?

Mark Hollanders (PDO) and Steven Bloemendaal (Shell)

AAPG/EAGE "Hydrocarbon Seals of the Middle East"

Muscat, January 18th-20th, 2016

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Petroleum Development Oman

Outline

- Introduction of PDO/Shell Risking Scheme
- Trapping Styles and Seal Definition
- Imperfect Seals and Retention
- Diagenetic Seals and their Timing of Formation
- Transient Effects – Define the Seal
- Unconventionals – Seal equals Reservoir
- Closing Remarks

Note:

This presentation is more intended to provoke thoughts than to give answers

PDO/Shell Risking Scheme

Some statements and clarifications:

- When people talk about "Risk", they often mean "Chance Factor" (CFs)
- Different companies use different risking schemes, or different definitions of the contributing elements
- Multiplying relevant CFs gives the Probability of (Geological) Success (PoS)
- Risking should be based on a geologic model

Elements considered when assessing the prospect PoS:

Charge CF

- What is the chance of having a sufficiently rich source rock present?
- Does the source rock of the correct thermal maturity for the desired HC phase?
- Is there a viable migration pathway from source rock to reservoir?
- Is the structure in place prior to charge timing?

Structure CF

- Is the mapped trap real?

Reservoir CF

- Is reservoir as described in volumetrics present in the mapped trap?

Seal CF

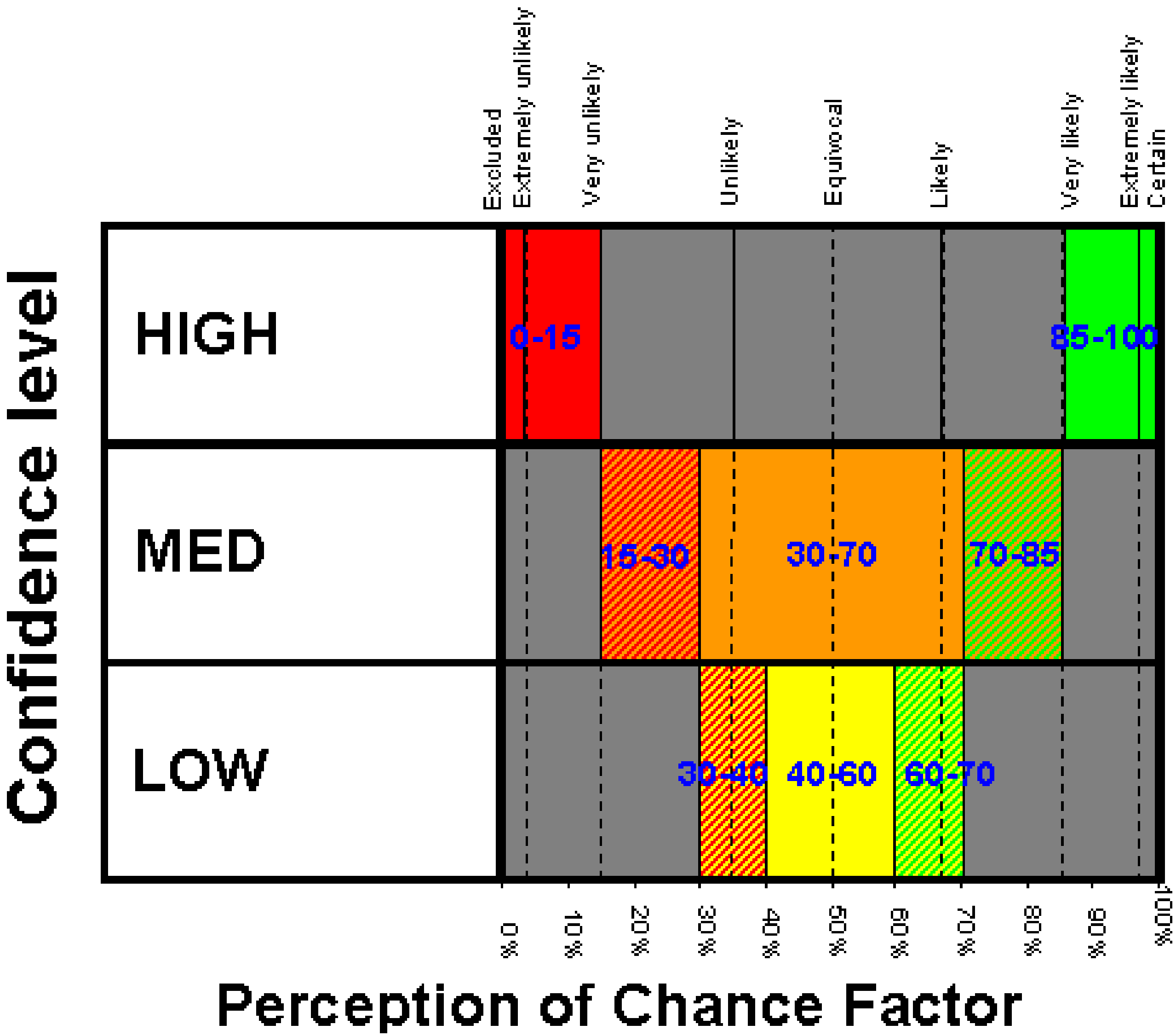
- Are the seal(s) at the crest* effective?

  * the spill-leak point statement is used to define the seal effectiveness away from the crest of the prospect

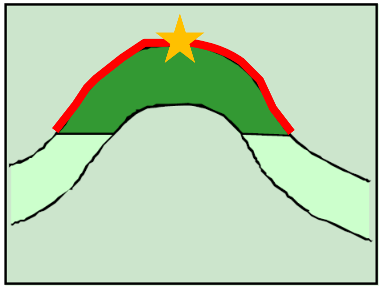
Recovery CF

- Can we produce as assumed by the recovery factor?

Confidence in Risking - The Bull-Head Matrix

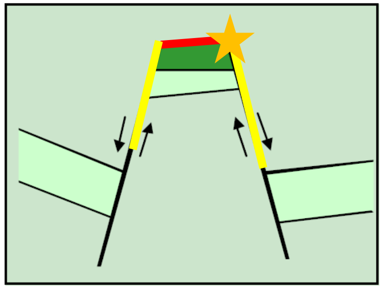


Trapping Styles and Seal Elements



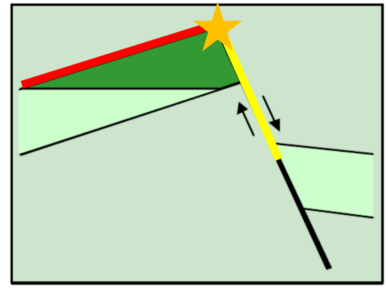
A. Anticline, dome

- top depositional seal



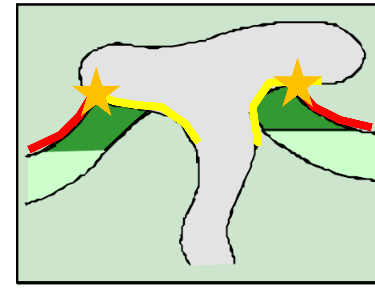
B. Horst

- top depositional seal
- lateral fault seal



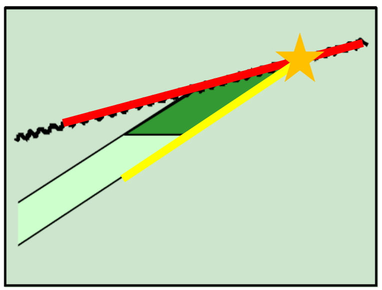
C. Rotated fault block (normal)

- top depositional seal
- lateral fault seal



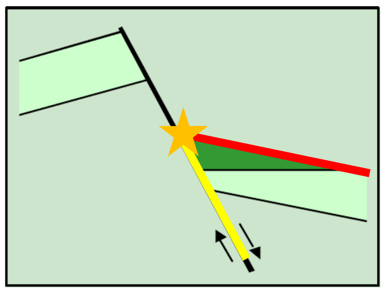
D. Traps formed by salt diapirism

- top depositional seal
- top/lateral salt diapir seal



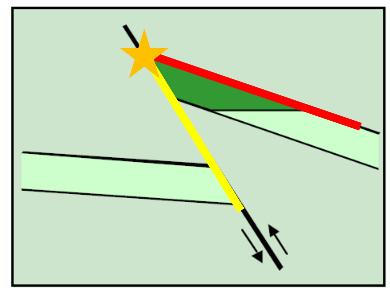
E. Trap formed by truncation

- top unconformity seal
- seat depositional seal



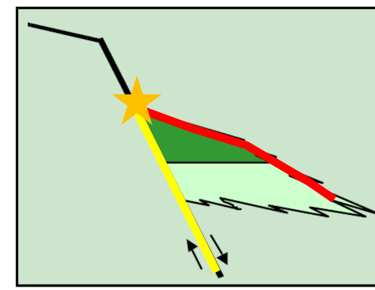
F. Downthrown fault block

- top unconformity seal
- lateral fault seal



G. Fault block (reverse)

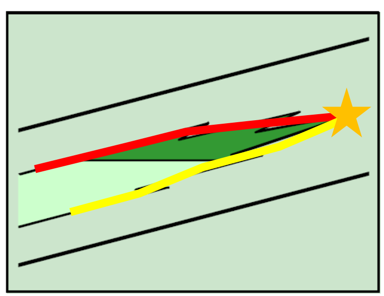
- top unconformity seal
- lateral fault seal



H. Combined trap mechanism

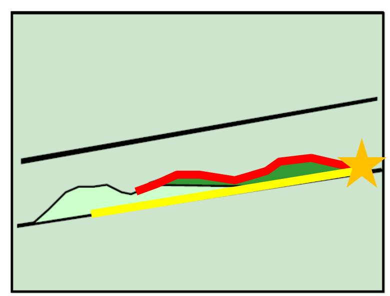
- top pinch-out seal
- lateral fault seal

*depositional: time-related
pinch-out: facies-related



I. Stratigraphic trap ("shale-out")

- top pinch-out seal
- seat pinch-out seal



J. Stratigraphic trap

- top pinch-out seal
- seat depositional seal

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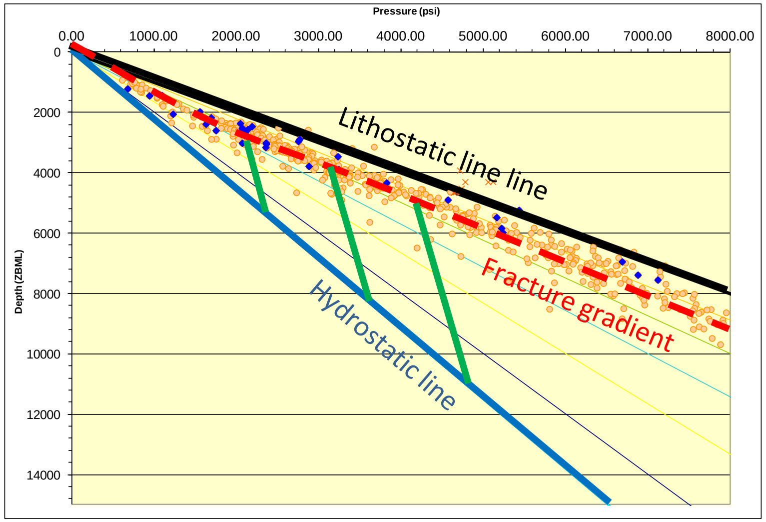
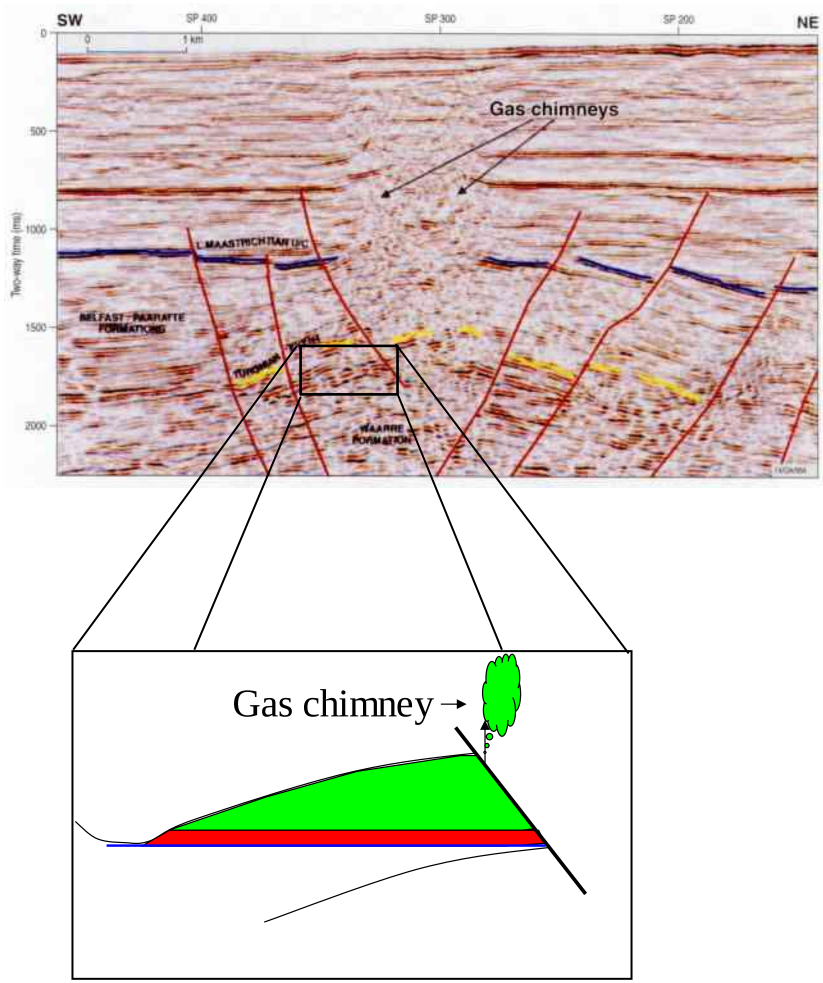
Modified after CCOP, 2000

There is (almost) no such thing as a Perfect Seal

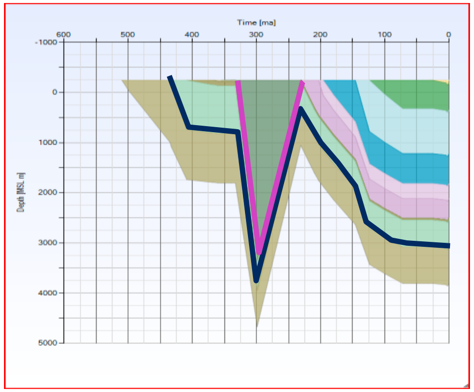


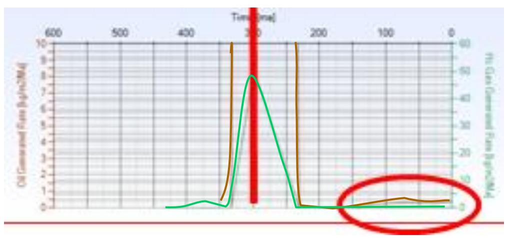


Seals will leak due to:

- Capillary pressure and entry pressure effects
- Preferential leakage of gas (gas chimney)
    - In the example to the right, despite ample gas charge, not all the oil has been flushed out and an oil rim is retained; this can be explained by differential leakage of gas, whilst the oil would not leak across the fault (below a leaky seal, the trap may be rich in oil)
- Hydraulic fracturing, limiting column height
    - Depending on depth and overpressures (see above)
        - See also next slide

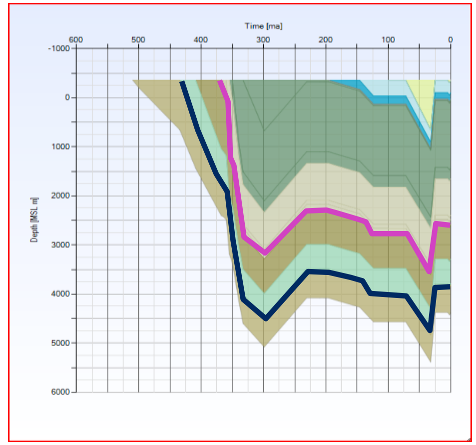
Retention – Seal Capacity Through Time

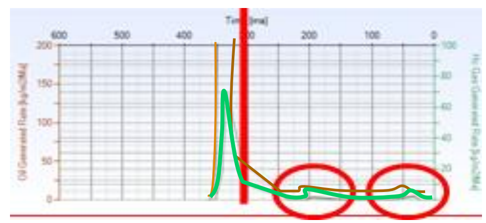




(Sub-)Basin A:
- Significant uplift after charge, with subsequent burial

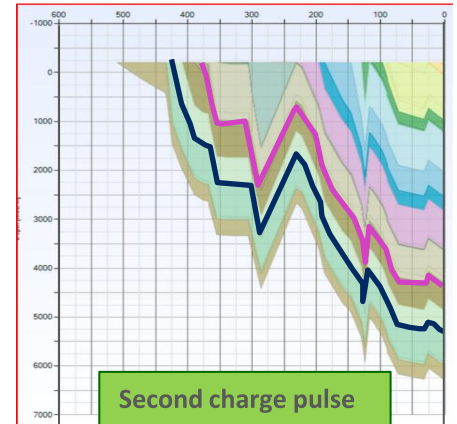
<u>No discoveries</u>
<u>Non-prospective</u>

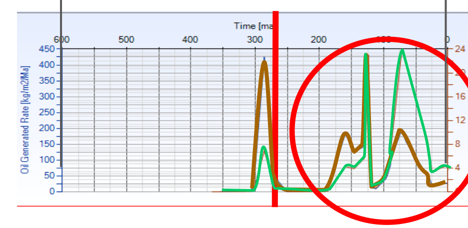




(Sub-)Basin B:
- Early charge, limited subsequent structuration

<u>Some discoveries</u>
<u>Moderately prospective</u>



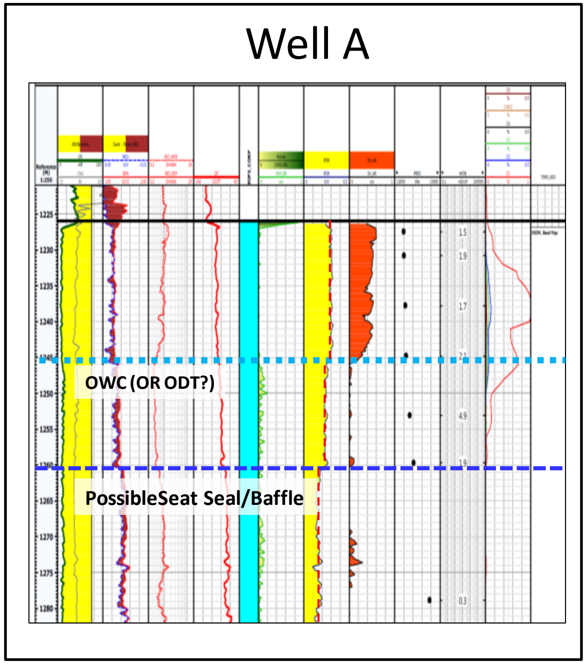


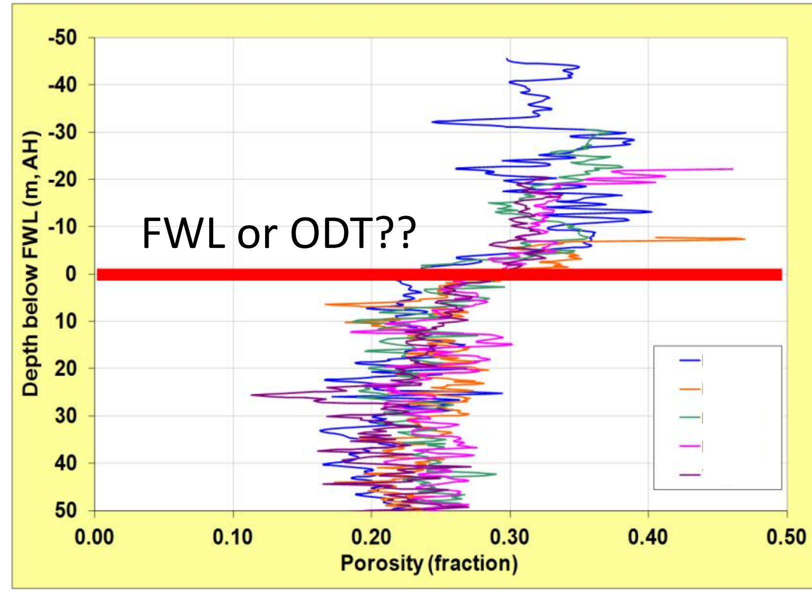
(Sub-)Basin C:
- Several charge pulses with recent charge

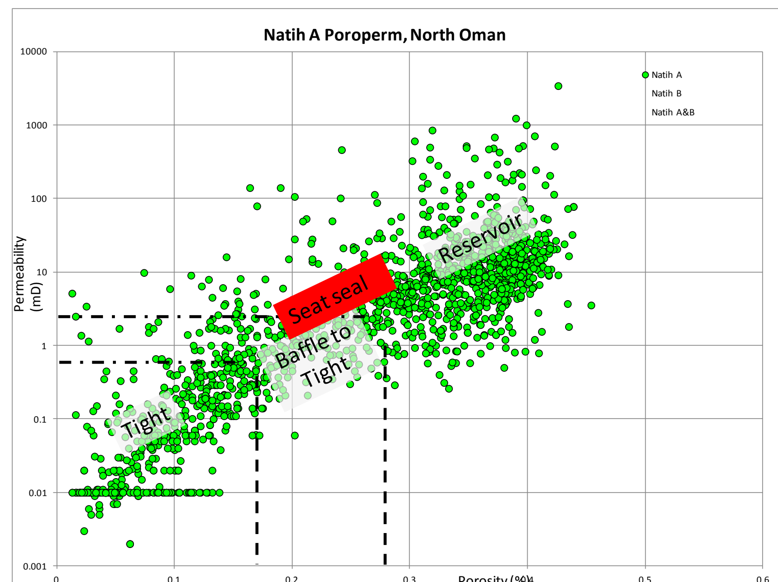
<u>Many discoveries</u>
<u>Highly prospective</u>

Similar reservoir/seal pairs, same source rocks, different structural history
<u>Different seal risk caused by different retention risk</u>

Seal "Creation" Through Time – Natih A Seat Seal (Oman)







Observations:

- Base of high oil saturation coinciding with porosity change
- Often no apparent structural closure
- Pressure data often inconsistent

Tentative explanation:

- Wettability changes through time
  - oil-wet vs. water-wet, leading to...
    - post-charge diagenesis variations between oil leg and water leg
- Post-charge structuration redefining trapping configuration

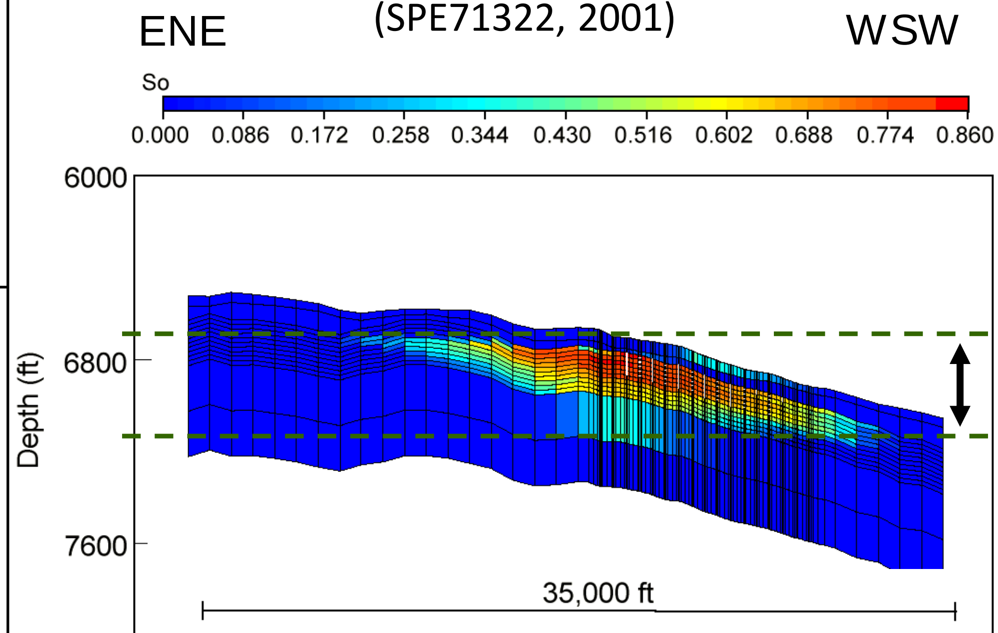
Upside potential when considering diagenetic (seat) seals in combination with post-charge restructuration

Hydrocarbons on the Move – Define the Seal

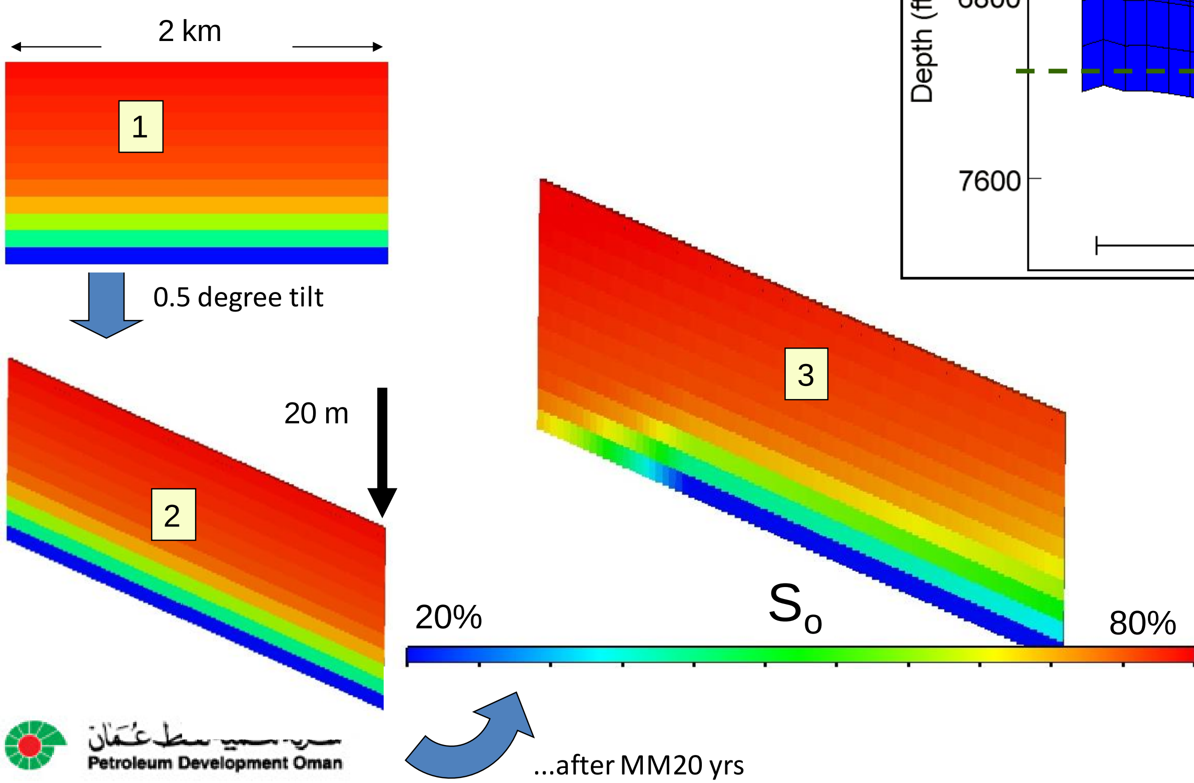
The pace of lateral oil migration in chalk is less than that of continental drift and", like plate tectonics, oil migration is still happening, making the present day situation only a snapshot in time (Kok et al., 2012)

Real example: Halfdan field North Sea Chalk

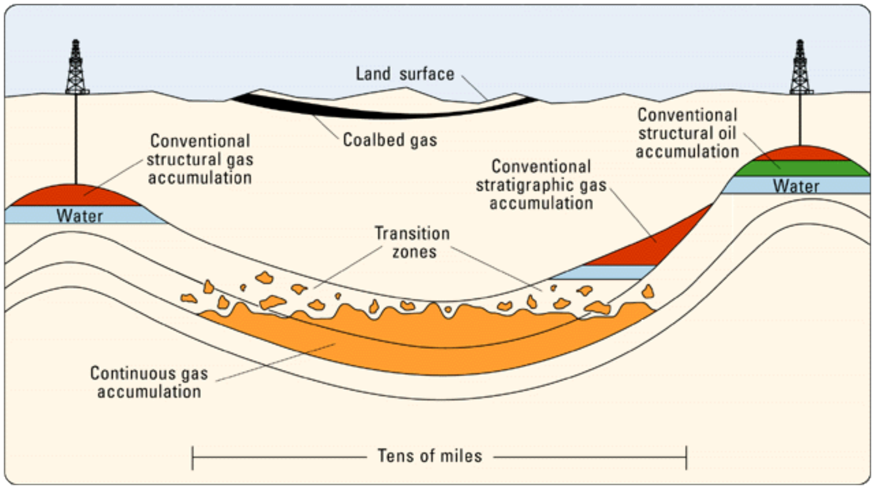
(SPE71322, 2001)



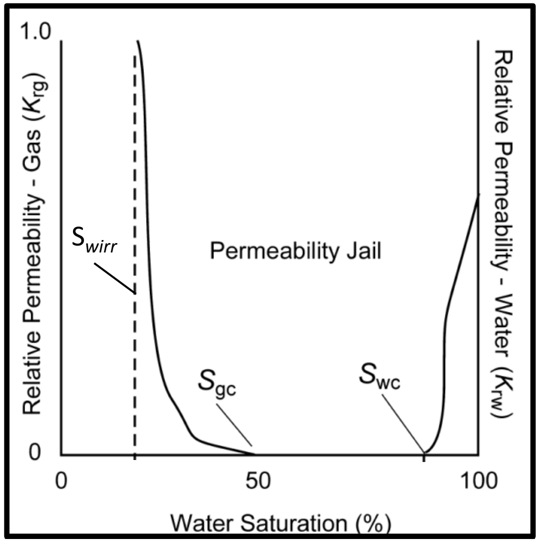
Modeling of transient effects



Basin Centered Gas and Shale Gas - The Permeability Jail



Schematic of unconventional (continuous) gas accumulations (after Schenk and Pollastro, 2002)



The concept of permeability jail (after Shanley et al., 2004)

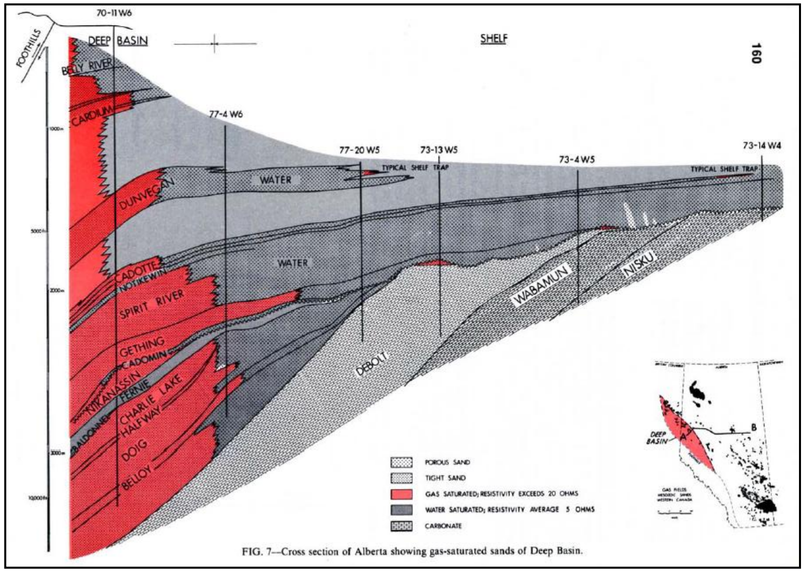


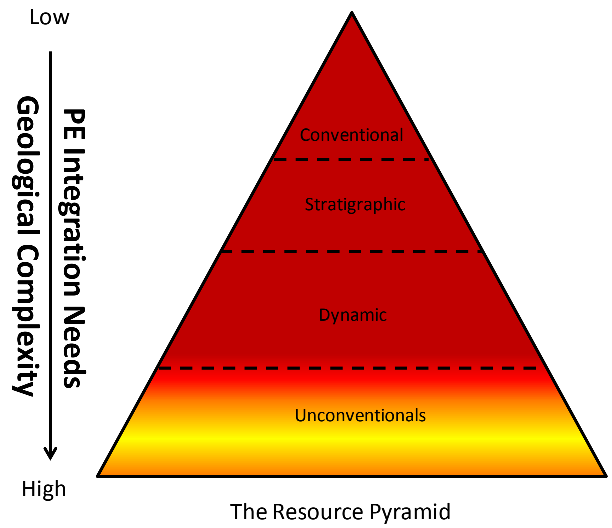
FIG. 7—Cross section of Alberta showing gas-saturated sands of Deep Basin.

Distribution of gas sands in the Deep Gas Basin (Masters, 1979)

The same rock is both reservoir and seal, depending on saturation

Closing remarks

- Assessment of seals and seal risk appears simple, but contains many subtleties
- Detailed understanding of the evolution of rock properties, linked to charge and structural history, is becoming ever more important
  - This requires closer integration of “traditional” exploration geology disciplines with petrophysics and reservoir engineering.



<u>To all Explorationists:</u>

Don’t feel hampered by “traditional” (risking) methodologies, but be creative in making sense of all data and information