[PS]Oil Below Water: Perched Water and High Order Sealing Elements, Implications for Exploration in Stratigraphic Traps*

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Abstract

Stratigraphic traps represent a major target for exploration, with the trap/seal often being the critical risk in evaluating prospects. Operators are especially interested in seismic evidence of the elusive “updip pinchout” of slope channel complex or slope fan reservoirs to de-risk the stratigraphic trap. Recently there has been mixed success in the exploration for these “classic” stratigraphic traps. We will present two concepts for stratigraphic traps that differ from this classical model, which have implications for both the identification and risking of prospects and the interpretation of well results.

The first of these concepts is recognition that higher order sealing components can combine to create the updip seal of an accumulation. These trap styles can be likened to a “frayed rope” where higher order depositional elements are represented by individual strands of the rope, terminating in different locations. The effect is that within a stratigraphic trap, the updip seal can be a zone with multiple sealing elements instead of a single, solid updip pinchout of the whole reservoir. We envision these higher order elements to be combinations of updip facies changes, updip/lateral pinchouts and lateral sealing elements in higher order channels.

The second concept is one that we call “translated stratigraphic traps”, where the updip extent of an oil accumulation occurs in a place other than an identifiable stratigraphic pinchout. In this scenario, hydrocarbons migrate laterally up a depositional system, with water being displaced downdip. In certain geometrical configurations, water cannot move further downdip, and becomes perched. Continued charge will build a hydrocarbon column downdip from the locked perched water contact. The ultimate result is an overpressured wet stratigraphic pinchout, and a downdip hydrocarbon accumulation. A well drilled to test the stratigraphic pinchout could therefore miss this potential accumulation.

The concepts presented here are not mutually exclusive, and are envisioned to occur at a variety of scales and in different combinations. Using well log, fluid pressure, geochemical and high quality 3D seismic data, we demonstrate the existence of a complex yet subtle stratigraphic trap in a turbidite reservoir that exhibits evidence of both of these phenomena. These stratigraphic trapping styles should be considered when assessing (or reassessing) stratigraphic traps within submarine slope channel complex reservoirs around the world.

Oil below Water: Perched water and high order sealing elements, implications for exploration in stratigraphic traps.

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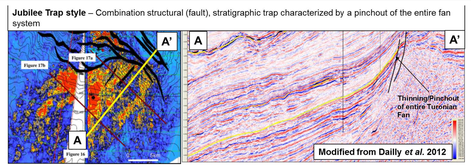
Introduction

Stratigraphic traps – a major target for exploration in deepwater Atlantic margins

- Trap/seal critical risk for prospects.
- Operators are especially interested in seismic evidence of the elusive "updip pinchout" of slope channel complex or slope fan reservoirs to de-risk the stratigraphic trap.
- The Jubilee field, discovered by the Mahogany-1 well in 2007, is an example of a structural/stratigraphic combination trap with a clear "updip pinchout" of the reservoir (Dailly *et al.* 2012).



Mixed success in chasing the "Jubilee play" around the margin.

- Post Jubilee "Gold rush" – 128 exploration wells drilled from 2007 to 2018, yielded a technical success rate of 52% and a commercial success rate of 23% (Westwood energy 2018).
- Technical failures typically attributed to migration or seal failure, while commercial failures are driven by reservoir quality or trap size.
- Work by Gerard (2009) shows that commercial volumes of hydrocarbons occur in low dip settings (3 and 12 degrees). Pinch out traps on steep slopes often have limited reservoir thickness at their crest, often coupled with lower reservoir quality and require an extremely large column before a commercial volume is reached, which may exceed seal capacity limitations.

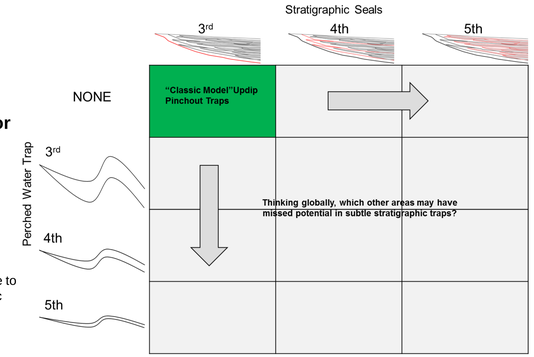
Chasing the updip pinchout has its limitations

- Often places where the clearest updip pinchout are observed on the steepest slopes, risk of steep columns exceeding seal capacity and reduced reservoir quality
- Going downslope into a low dip realm in a slope channel reservoir increases the chance of improved reservoir, and reduces column pressure on the seals, but require some thinking to define traps.

Going Upslope… Chasing the Pinchout	Going downslope…. Defining a trap
• Seismically defined edge/pinchout • May have better charge focus	• Better reservoir • May be closer to the source kitchen • Top seals have less column pressure.
• Steeper slopes build bigger columns, more pressure on top/lateral seal. • Reservoir quality may be poorer in upslope areas • Increased migration risk if lateral up the slope system.	• Increased updip seal risk. • Need to define a trap – new ideas required.

We present two concepts for stratigraphic traps with important distinctions from the classical "updip pinchout" model.

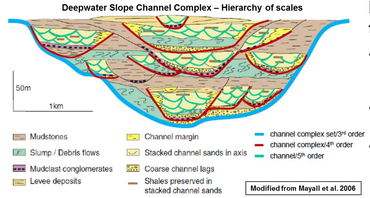
- Higher order Stratigraphic Traps
- Perched water traps
- These may act separately or combine to create a variety of subtle stratigraphic traps in deep water slope systems.

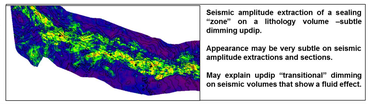


Higher Order Stratigraphic Traps – The "Frayed Rope"

Deepwater slope systems are often composite features.

- For the purposes of this paper "order" refers only to the scale of observation (no inference to timing or sequence stratigraphy).
- A 3rd order channel complex set (which often forms a single seismically mappable package) is often comprised of a series of stacked 4th order channel complexes and 5th order channel elements.
- The 4th and 5th order channels may be at the "geobody" scale of seismic characterization, or may be sub-seismic.



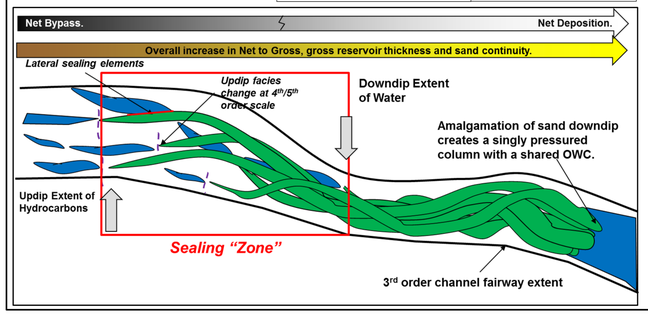


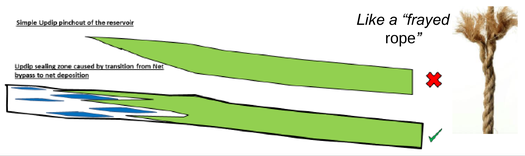
Higher order sealing components can combine to create the updip seal of an oil accumulation.

- These trap styles can be likened to a "frayed rope" where higher order depositional elements are represented by individual strands of the rope, terminating in different locations
- Within a stratigraphic trap, the updip seal can be a zone with multiple sealing elements instead of a single, solid updip pinchout of the whole reservoir.
- These higher order elements can be combinations of updip facies changes, updip/lateral pinchouts and lateral sealing elements in 4th or 5th order channels.

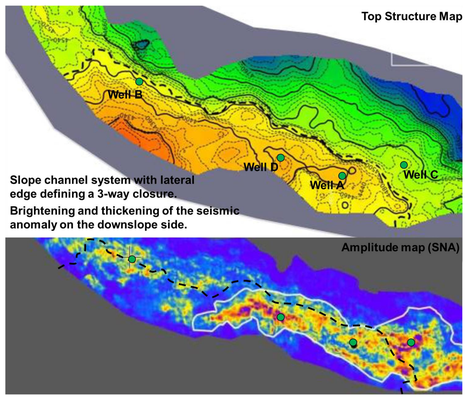
Certain locations within the slope channel system may be more prone to developing sealing "zones".

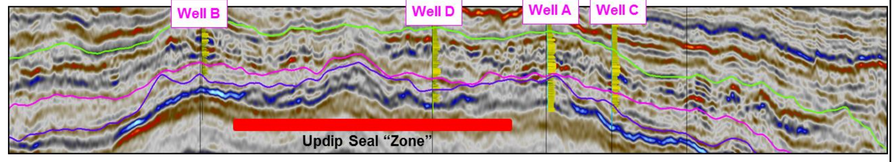
- Along axis changes in depositional style as a result of changes from net bypass to net deposition at the fairway scale which may be triggered by interaction with deeper structures
- A channel fairway in net bypass has increasingly isolated sand bodies upslope – individual 4th and 5th order channels may pinchout far downdip of a pinchout of the "fairway" -3rd order.
- These individual strands have different seals in different places, may not appear as a clear "updip edge" on seismic, may be a subtle dimming of amplitude over several kms.

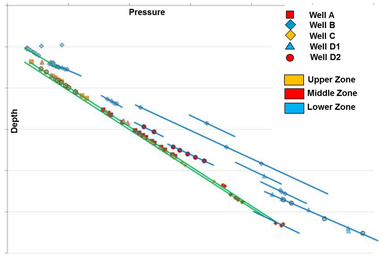


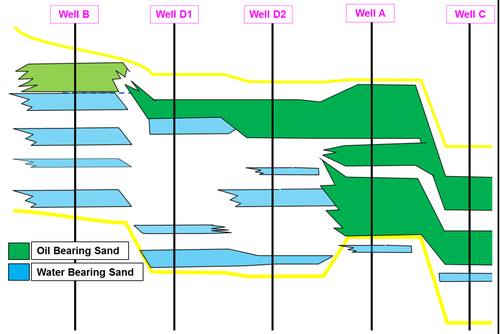


Case Study – Deepwater Slope Channel Reservoir







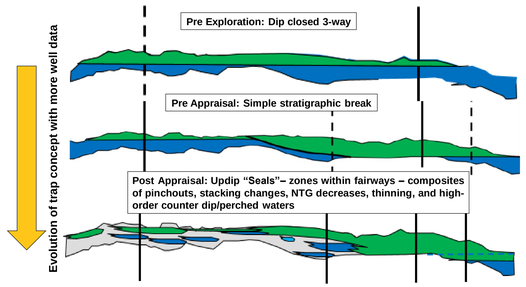


Deepwater Slope Channel Complex Reservoir

- High porosity, high permeability turbidite sandstone reservoir.
- Seismic amplitudes define lithology/porosity, no fluid effect.
- Oil accumulation commonly pressured across wells (A,C,D), and ~15 psi offset in Well B. Oil biomarkers and isotopes indicate a common origin and shared charge history.
- Lateral pinchout on the SW lateral edge, no updip pinchout observed, channel system continuous for 10's of km upslope.

Evolving trap concept as prospect was drilled and appraised.

- Amplitude anomaly with thickening reservoir identified but deemed too risky as a pure strat trap – no updip pinchout identified. However 3-way closure against lateral seal made prospect risk acceptable to drill.
- Well A found a single pressured oil column, with LKO below spill point for the 3-way. OWC defined by oil/water pressure intersection and used to plan Well C and D.
- Well B drilled and found a separate oil column ~15psi overpressured from Well A, with overpressured water below (4 aquifers).
- Pinchout/stratigraphic break postulated to explain major elevation change of OWC and pressure offset in oil column.
- Well C found oil below prognosed OWC, Well D found water above the OWC and above the "strat break" – oils all commonly pressured with Well A.
- Pressure, geochemistry and detailed seismic interpretation intergrated to reassess the trap and fill history of the reservoir.
- Evidence points to a subtle stratigraphic trap where the concepts of higher order sealing elements and perched water are both important.

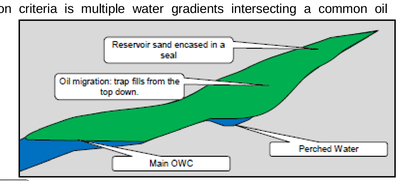


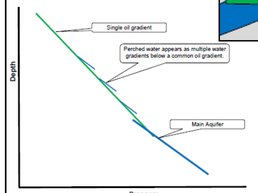
Classical concepts aren't discarded/invalidated, but they are inadequate to fully explain our observations and our understanding of the trap.

The Perched Water Trap

Perched water is any water unable to escape from the reservoir during hydrocarbon migration.

- Typically occurs in reservoirs with strong top and base seals.
- Perched water can be set up by a small saddle (or breakover), or by a sand pinchout (in short: the inverse of any trapping configuration where you can find hydrocarbons).
- The only definitive recognition criteria is multiple water gradients intersecting a common oil column.





Perched water can trap an oil field downdip of an updip seal. These processes can "Translate" a an oil accumulation away from the stratigraphic seal elements that control it.

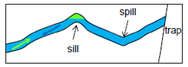
The key elements:

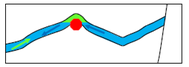
- Need a trap and seal somewhere "updip" – elevation doesn't matter
- Need a sill point (may be structural or stratigraphic)
- Critical relationship to set up the "trap" is height of sill to depth of spill. Exacerbated in flat structures

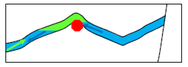
Water expulsion during charge is a critical process

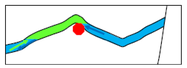
- Need to apply inverted thinking: gravity and drainage as important as buoyant forces and charge
- Explanation for strange observations in reservoirs: sands that appear "flushed", high pressure water zones, inconsistent hydrocarbon/water contacts.

Scenario A – Development of a Perched water trap in a structural configuration.



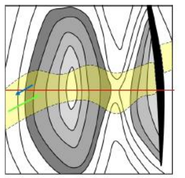




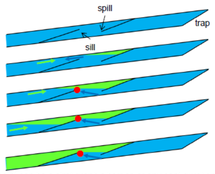


Assumes lateral migration from downdip and perfect seals

- Assumes lateral hydrocarbon migration from downdip travels up a slope depositional system with excellent top and base seals, with water being displaced downdip.
- Structural sill prevents water from moving downdip any longer, and thus becomes perched.
- Continued charge will build a column downdip from the locked perched water contact, and the pressure will increase in the perched water updip from the hydrocarbon column.

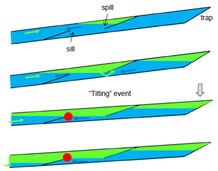


Scenario B – Development of a Perched water trap in a stratigraphic configuration.



- Sill point can be a stratigraphic barrier, or any configuration that can trap small oil accumulations.
- Stratigraphic barrier may be sub-seismic and may lead to incorrect interpretation of the updip extent of a hydrocarbon accumulation.
- As the hydrocarbon column continues to build, pressure will increase in the hydrocarbons updip and in the perched water beneath it.

Scenario C – Post emplacement tilting of a perched water trap.



- If sill and spill are similar depth, slight "tilting" can rearrange accumulations
- •Continuous columns may become segmented
- •Separate columns formerly sitting on common aquifer now connected by a perched water zone
- Timing of tilting to trap fill matters. Scenario C above can result in separate oil columns that appear isolated but are connected via a perched water. Tilting in the other direction can cause water to spill over a sill, and run down dip, flushing formerly charged zones .

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Westwood Global Energy Group 2018- Jubilee to Liza The Keys to Unlocking Commercial Success

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