Migration Lag - What is it and how it affects Charge Risk and Fluid Properties*

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Abstract

Traditionally one of the main goals of petroleum system analysis is to determine timing of petroleum generation relative to timing of trap formation. The idea is that if the trap formed later than the oil generation phase, it may miss the oil charge, or capture the late gas phase rather than oil. In recent years, there have been many oil discoveries in reservoirs that are deposited after the main oil generation phase. It seems that there is a time lag between oil generation and charging of reservoirs. In many cases, such lag has been estimated to be between 5 and 20 million years. In this paper, we will examine the mechanisms for this apparent lag, and how we could account for it in assessing petroleum system risks. Once we understand how it works, we may see that the processes, which cause the lag, can significantly affect charge risk and fluid type prediction.

During hydrocarbon generation, the initial HC fluid generated is taken up by the source rock itself: by adsorption to the organic matter and partially filling the pore space in the source rock interval. Primary migration out of the source rock then happens. The lag time between the beginning of generation and primary migration (primary migration lag) depends on the rate of generation, and the volumes required to satisfy adsorption and saturation thresholds. Typically, this may take about 10 to 20% of the entire duration of the hydrocarbon generation window, or more if the source rock has more reservoir-like properties (inter-bedded siltstone, organic porosity, etc).

Once the oil enters the first carrier bed, some of the initial volume is used to establish the minimum saturation needed to continue migration, and some of it is used to fill the micro and macro traps before it reaches the potential trap we may drill. This

time lag depends on the rate of generation (again), and the saturation and thickness of the “waste zone” formed by the micro traps, and the size and number of larger “traps” it has to fill before reaching our target trap. If the target trap is not at the first carrier level but shallower, then the oil has to vertically migrate some distance to reach our trap. In that process, it also has to fill the sand intervals between the first carrier bed and the trap to either spill point or seal capacity. Time will again be consumed as these intermediate traps are being filled. Observation and simple estimates will show this time can be very significant.

Globally, there is a distinct distribution of fluid types in many basins, that the deeper fields are more likely to be gas, and shallower fields are more likely oil. This is also true laterally that up dip traps are more likely oil and deeper traps in the basin enter are more likely gas condensates. I believe these are at least partially a result of the migration lag process.

Reference Cited

Hao, F., X. Zhou, Y. Zhu, X. Bao, and Y. Yang, 2009, Charging of the Neogene Penglai 19-3 field, Bohai Bay Basin, China: Oil accumulation in a young trap in an active fault zone: AAPG Bulletin, v. 90/2, p. 155-179.

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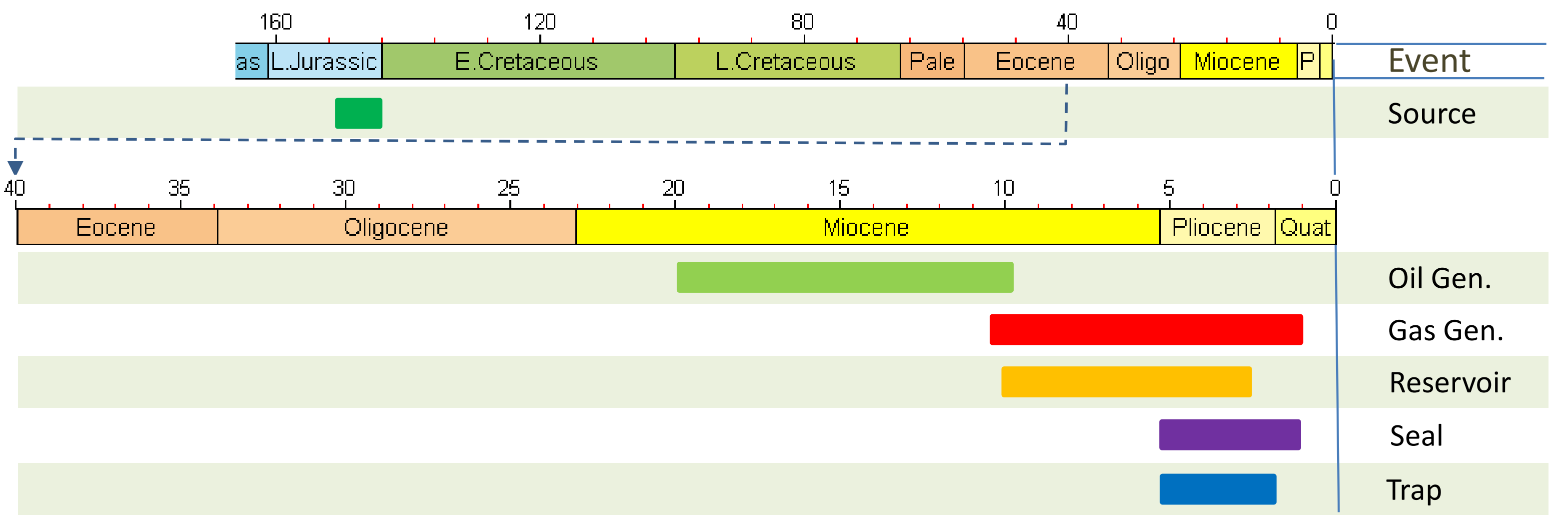
Introduction

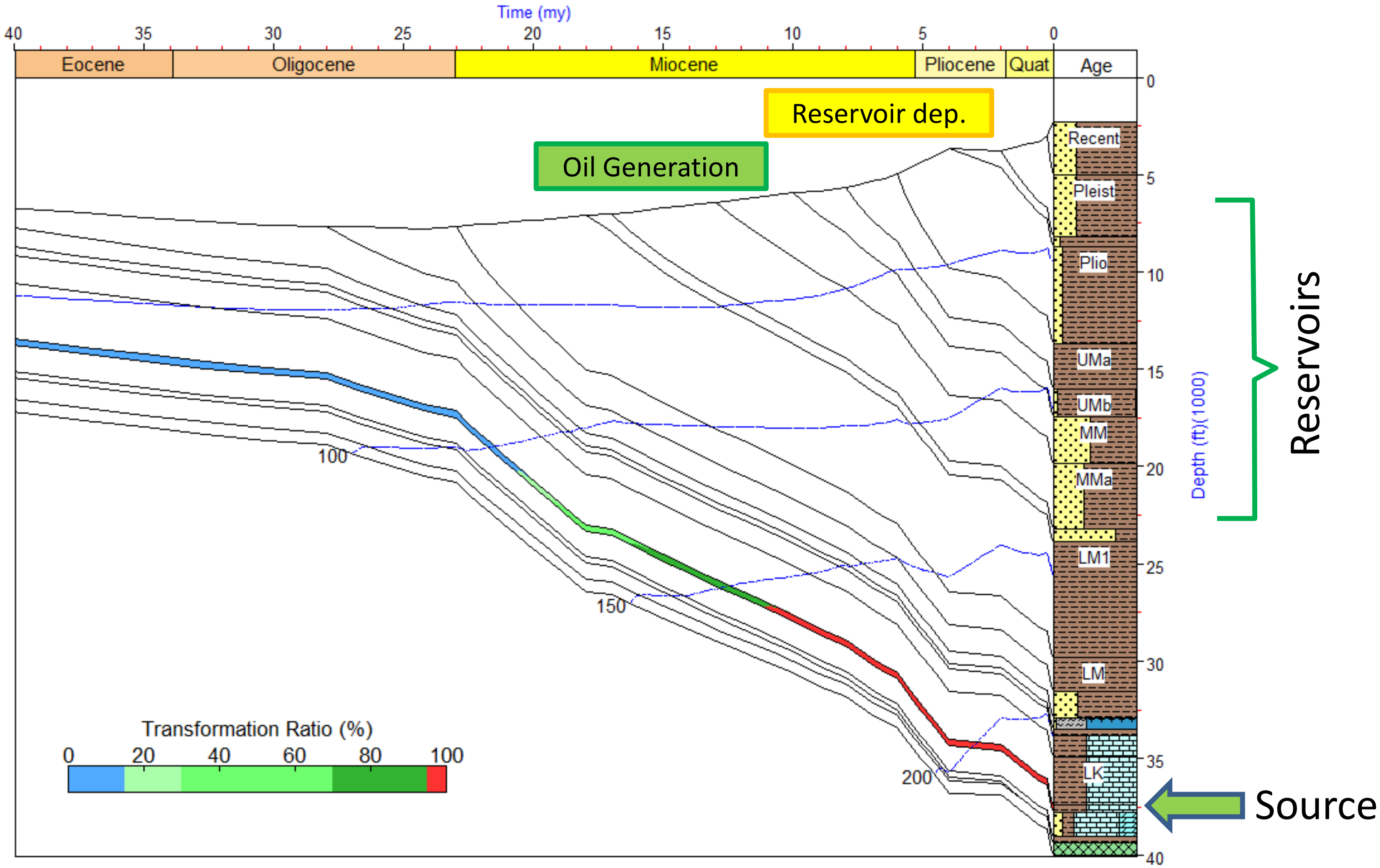
- The literature is full of articles emphasizing timing of generation relative to trap or seal formation, and people want to know when generation occurs and exploration managers are worried that the source rock may be past oil window, and over mature.
- However, more and more examples show that reservoirs can receive charge from fluids generated before trap, or seal formation, sometimes even before the reservoirs are deposited.
- In the two examples presented here, oil generation happened 10 to 20 million years before reservoirs were deposited. The source rock is at temperatures above 200 °C today, and the younger reservoirs produce low maturity, low API and low GOR oil.
- Another good example is the West of Shetlands (Foinaven and Schiehallion oil fields). The Jurassic source rock enters gas window at end of Cretaceous, but the lower Tertiary reservoirs contain under saturated oil. The “motel” and remigration was proposed in the 90s to explain the observation. I believe, by reasoning presented here, in different degrees this should be the normal process in all basins.

The Petroleum System Chart

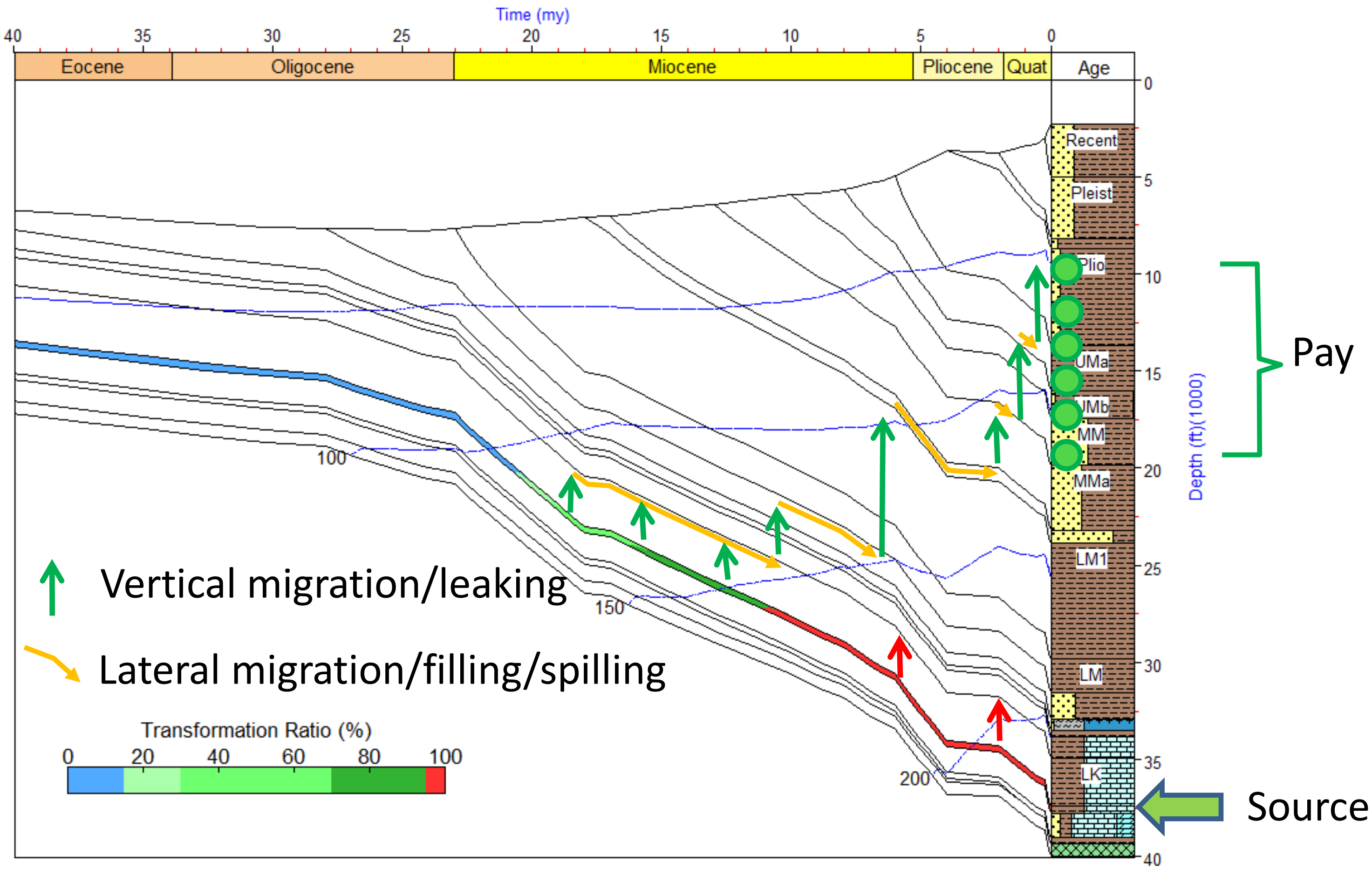


- ❑ Reservoirs were deposited post oil generation.
- ❑ Trap and seal formed in last 5 millions years.
- ❑ Should we drill / farm in the prospect?
- ❑ What will we find in the reservoirs (water, gas, oil)?

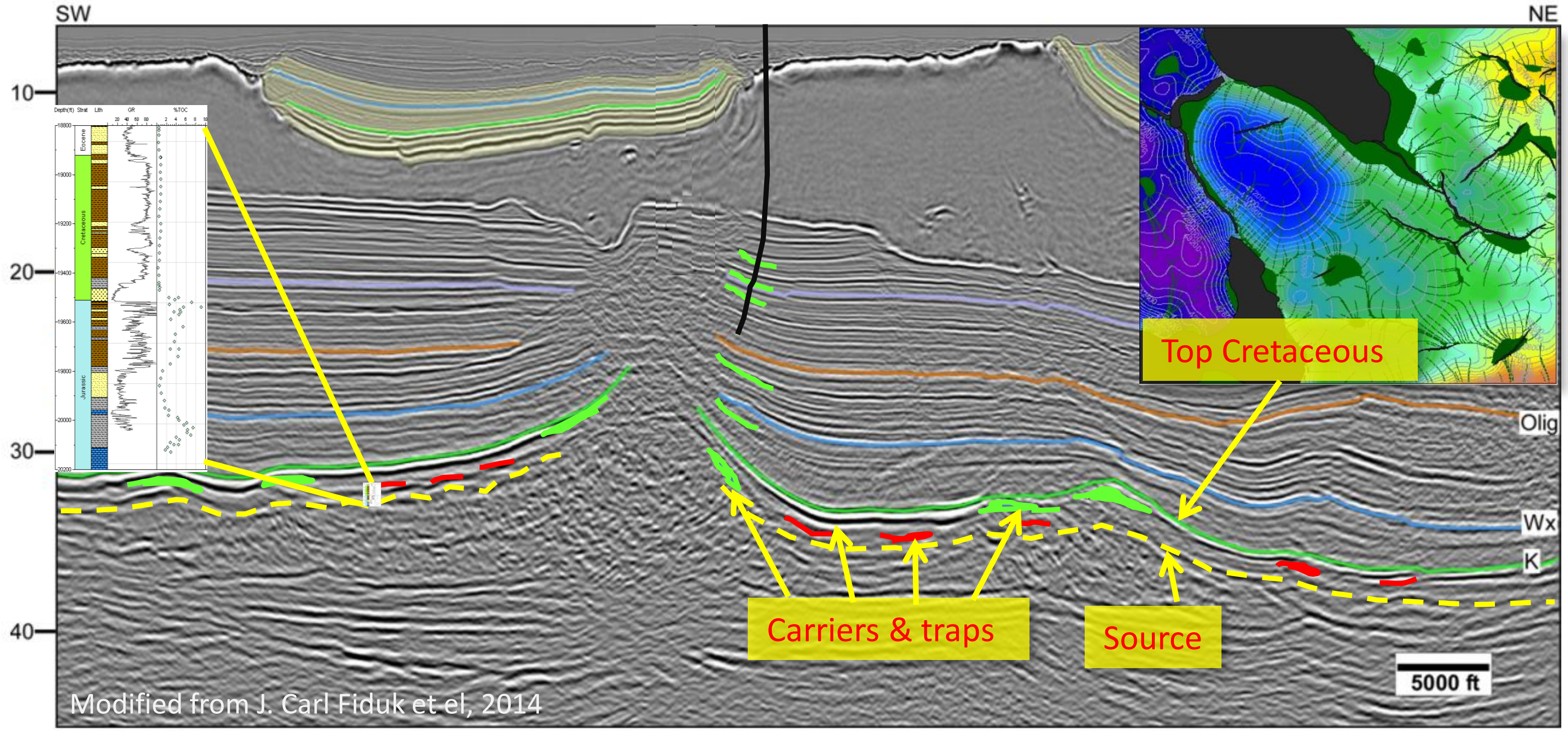
Example 1. This is a typical deep-water GoM burial history showing timing and maturity of the Tithonian source rock. It went through oil window between 10 and 20 million years ago. The main reservoirs in this area are middle Miocene, and some as young as Pleistocene.



Prevailing explanation of this phenomenon is the so called "migration lag". The early oil generated at about 15 million years ago, migrates into the first carrier beds immediately above the source. It then laterally migrates, fills and spills and accumulates in the higher locations. While it is doing that, the carrier bed its self is buried deeper. When the seal capacity is reached, it continues to migrate up, to the next carrier. At each level, a few millions years is spend to fill the rocks. Only in the last 5 million yeas or so, the Miocene and Pliocene reservoirs are being filled with low maturity oil, while the source is generating gas to flush out the oil in the first carrier.



Migration Lag: Early Generated Volumes of HC consumed by Carrier Beds



- ❑ Retention in source rock and first carrier intervals consumes significant amount of hydrocarbons in structure and stratigraphic traps (5-30 mmboe/km2 by my estimate) before it enters the lower Tertiary formation.
- ❑ Additional retention by filling & spilling in carrier beds in the lower Tertiary further delays entry into the Miocene reservoirs.

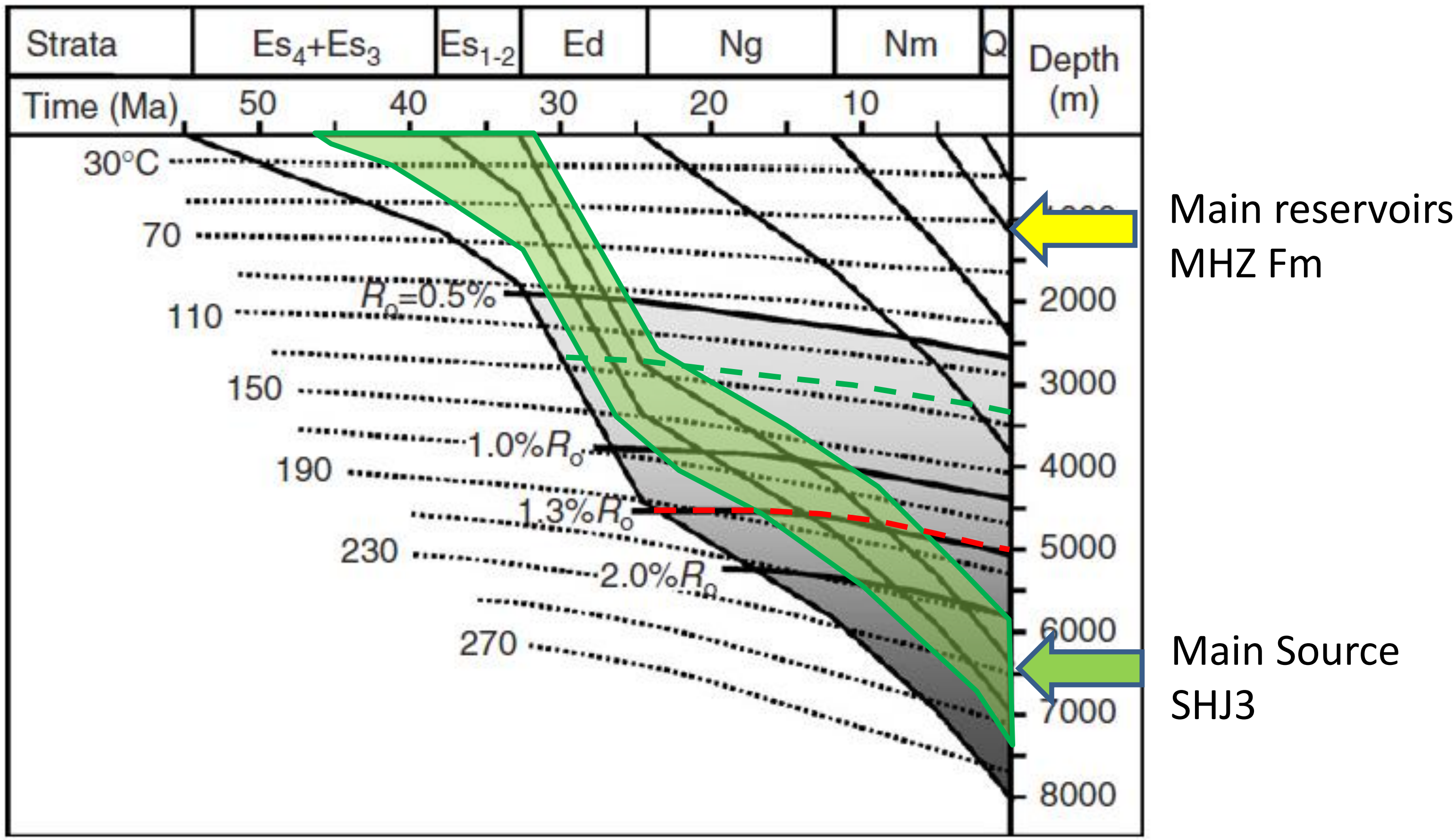


Fig. 6. Burial and thermal histories for rocks near the Bozhong depression center (Well BZ2 in Fig. 1(A)).

Figure modified from Fang Hao et al.

Exampel 2. Bohai. This example shows that although the source rock is in the gas window today, and went into gas window 10-20 million years ago (see next slide), the main reservoirs in the Ng/Nm (Pliocene) reservoirs are mostly low maturity oil in the region.

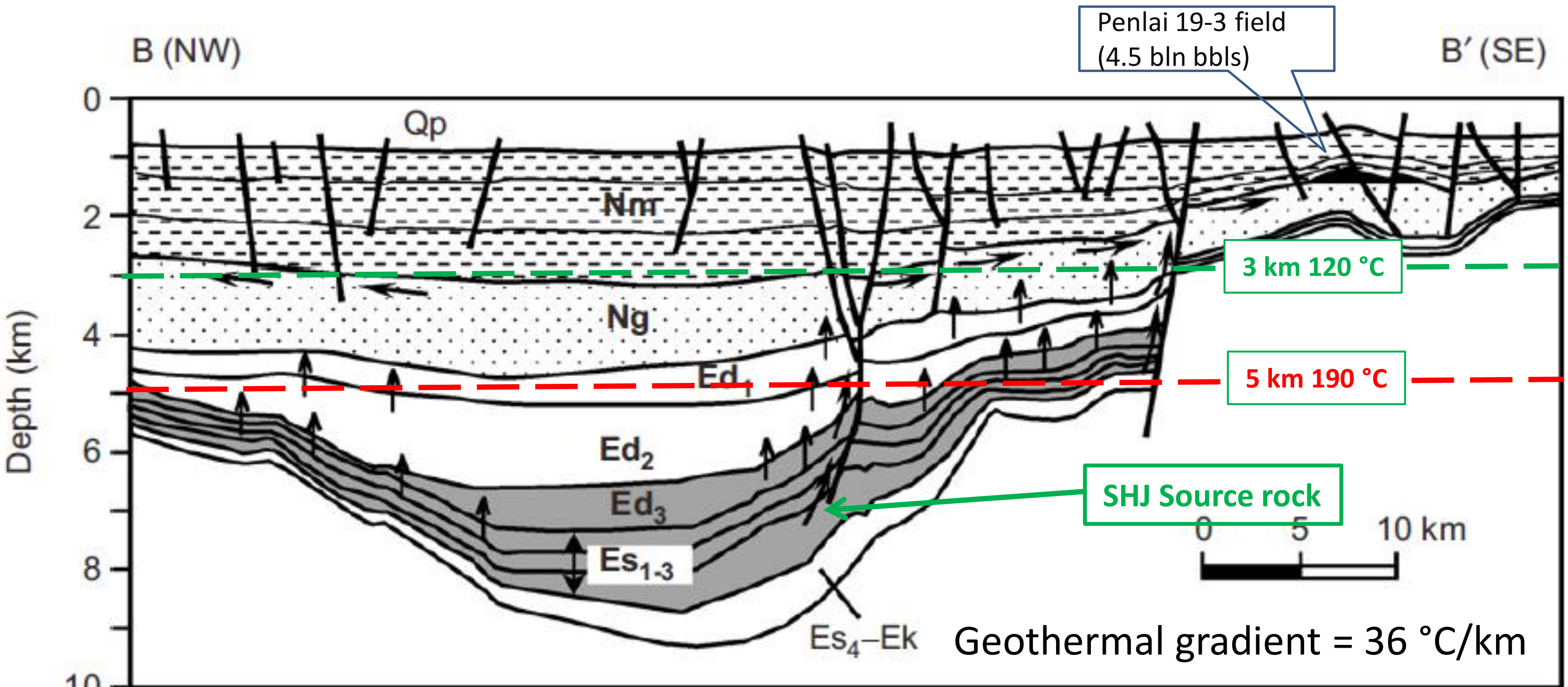
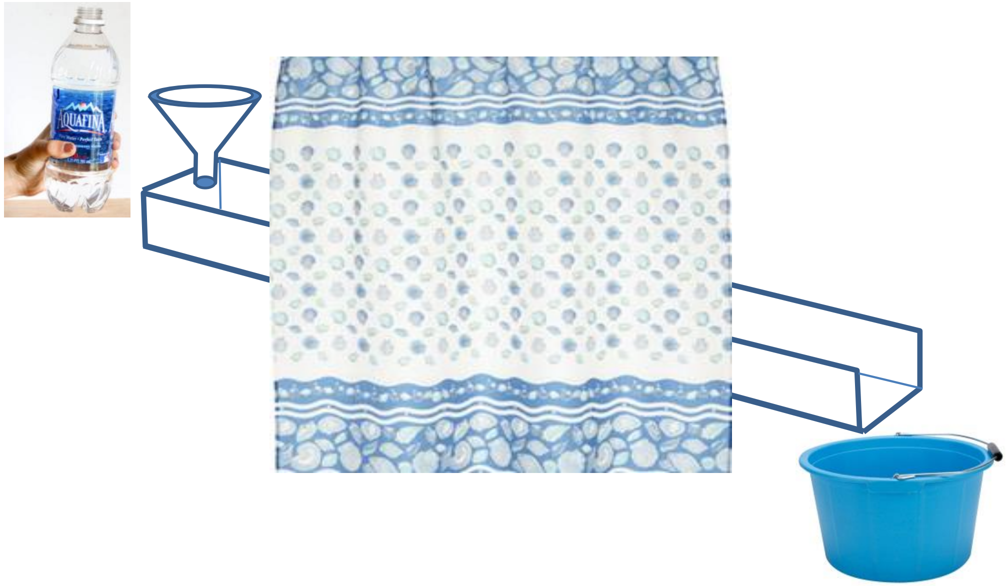


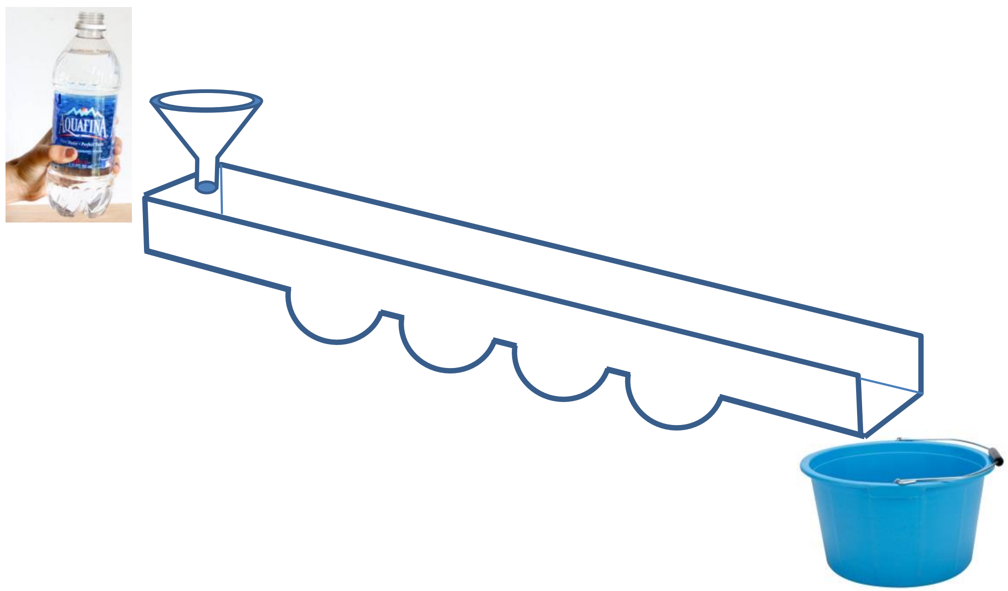
Figure modified from Fang Hao et al, AAPG Bulletin, v. 93, no. 2

How Long does it take the water to reach the bucket?



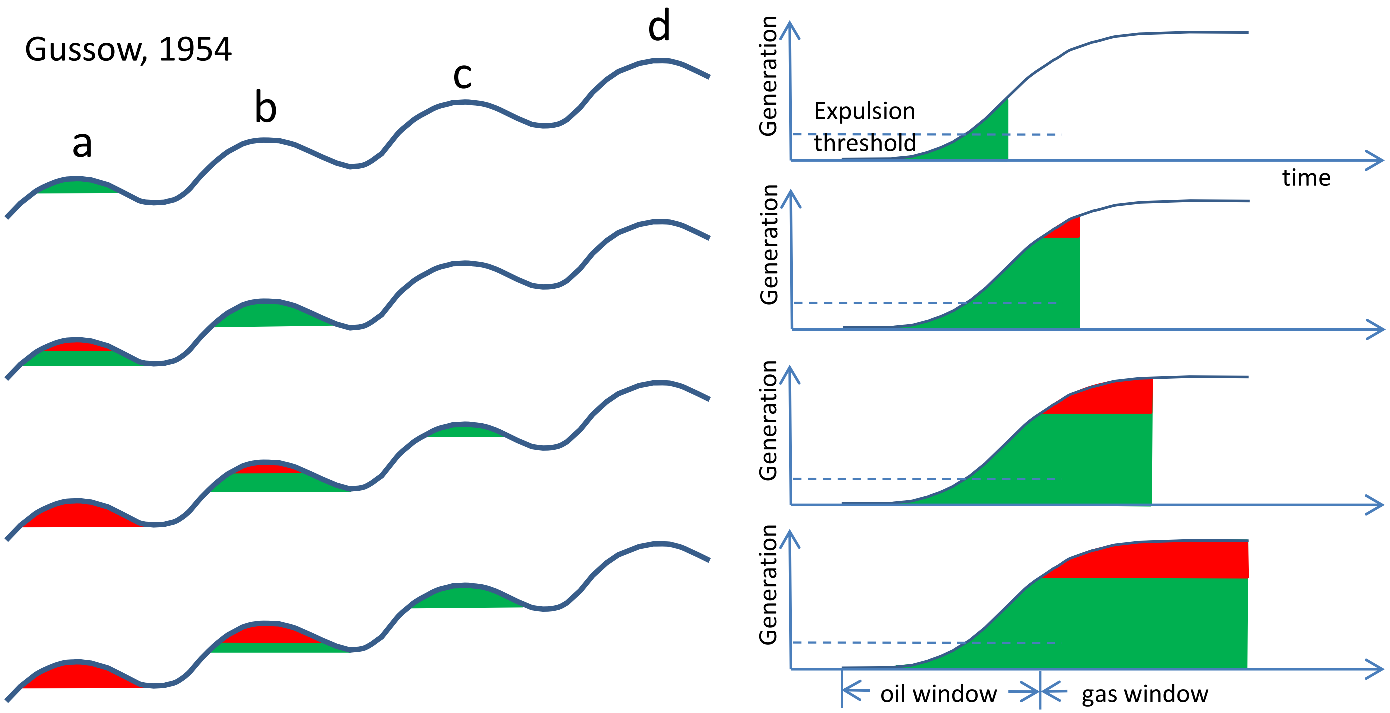
We have to have the bucket before we pore, right?

How Long does it take the water to reach the bucket?



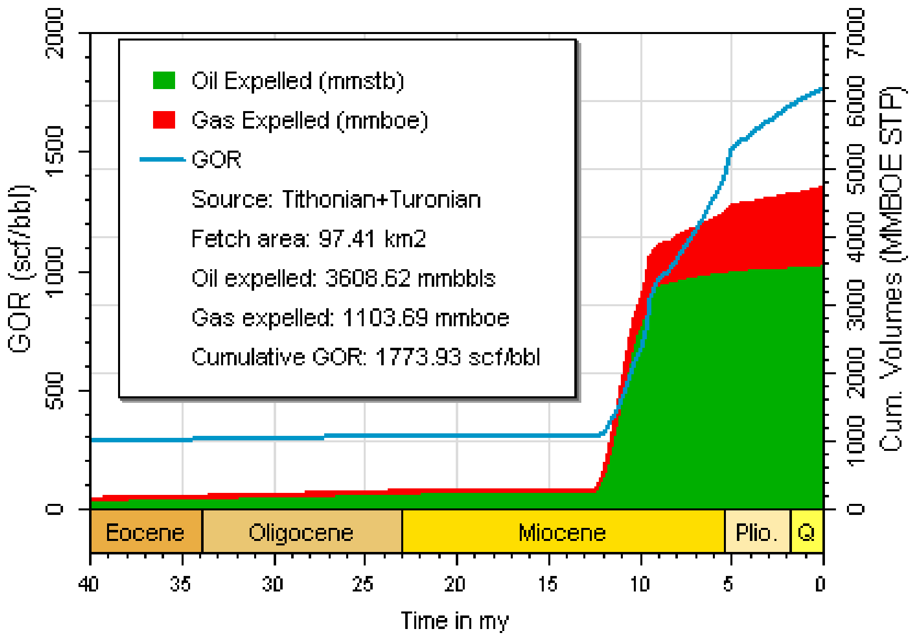
The bucket may not receive any water as there may not be enough water to reach it.

Timing of Generation and Timing of “Charge” are Different: Migration Lag

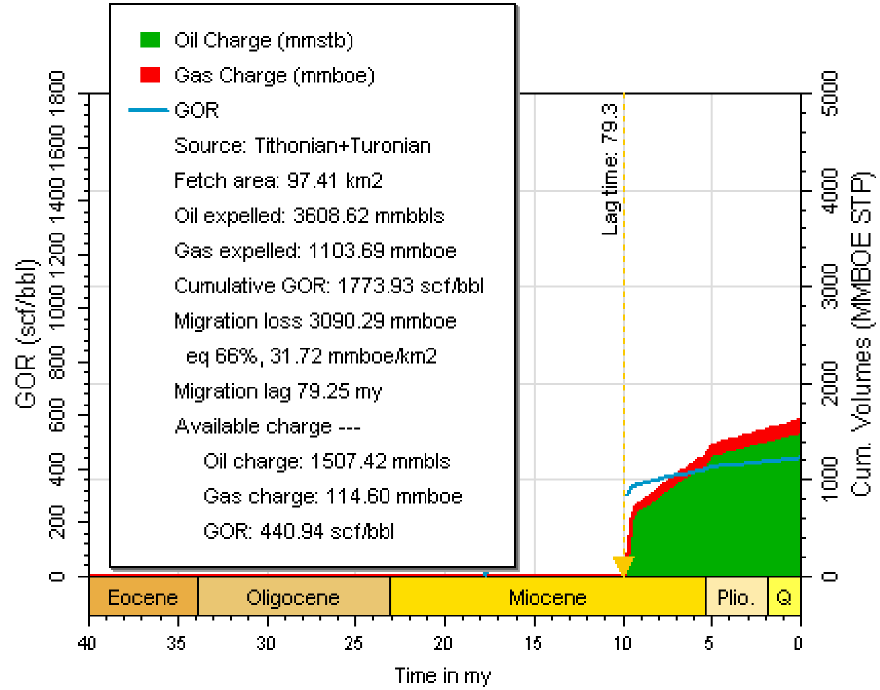


- ❑ Trap filling time depends on where it is in relation to the kitchen. Oil continues to migrate and fill traps while gas is being generated in the kitchen.
- ❑ There are many traps, micro/macro, structure/stratigraphic down dip from these traps that can much further exacerbate the timing problem.

Accounting for migration lag

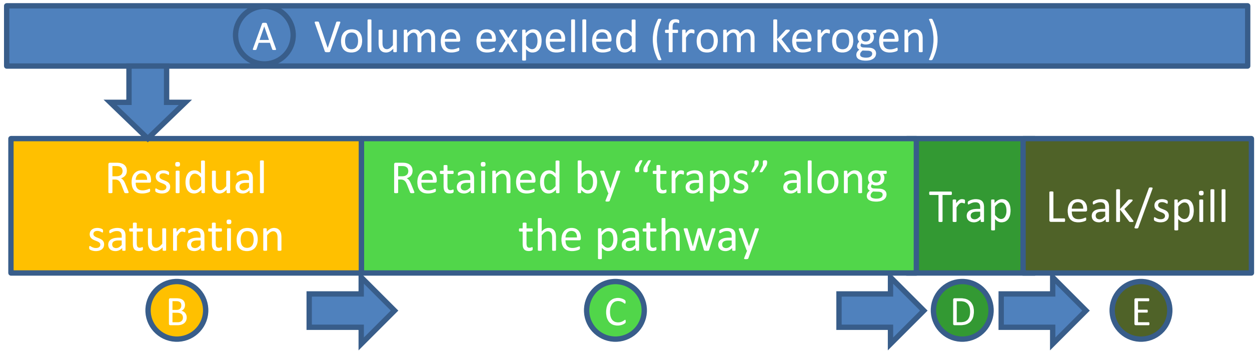


No Lag



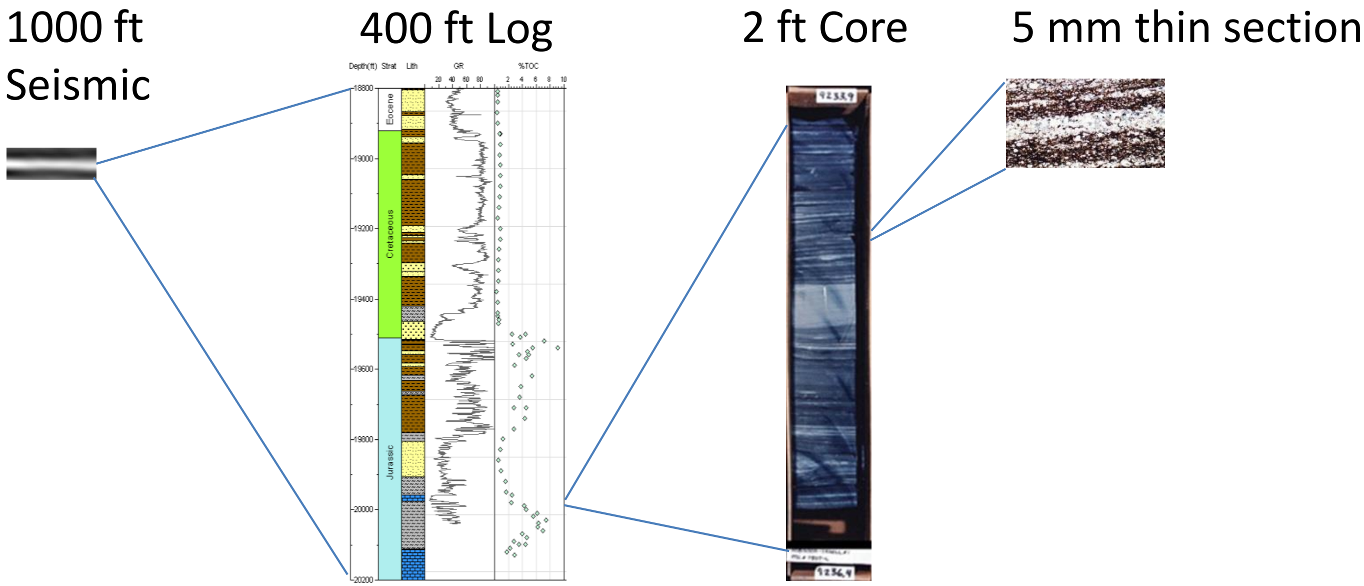
Lag

Charging Order of the Migration Process



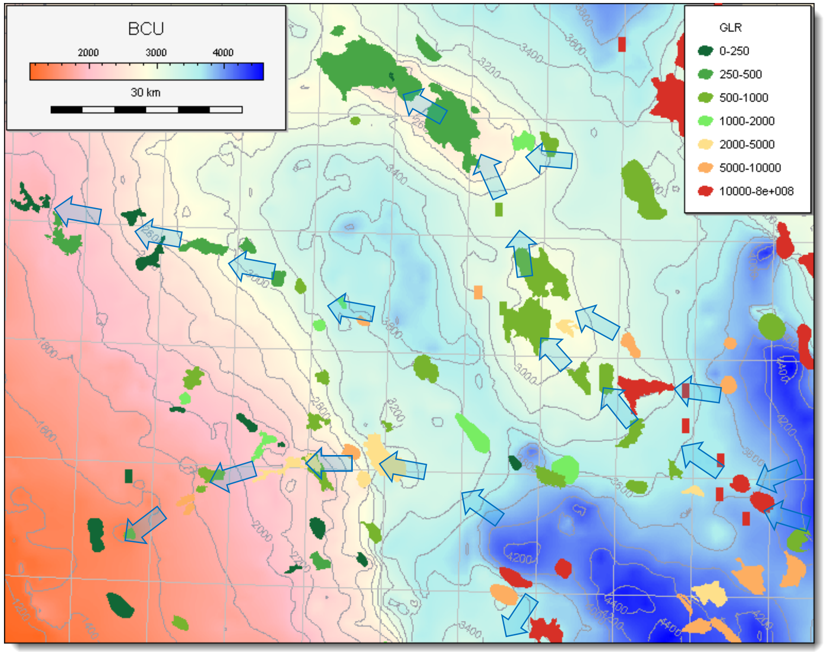
- Available volume, expelled from kerogen after satisfying adsorption, will first need to saturate pores within and near the source rock (B, unconventional) and then fill the migration paths (C, micro/macro traps and residue saturation) before reaching the trap (D, our prospect). If trap is filled, then leak or spill occurs (E).
- If volume expelled is less than B + C, our trap is not charged. This is a high probability when source rock is average or weak, or the target trap is up dip or shallow.
- Probability of half filling our trap is small as the expelled volume has to be just more than B + C, but less than B+C+D. Don't worry about your trap being full or not, worry about if it will be filled at all.

Retained Volumes: Limitation of Data & Uncertainty



- Retained volumes depends on the <u>heterogeneity and structure complexity</u> of the source and carrier beds.
- Most of that is below seismic resolution, and even log resolution.
- For example, 10% saturation over 200 meters retains 10 mmbls/km2
- Eagle Ford (core and thin section) retains ~50% of the hydrocarbons generated (~15 mmbls/km2 over 30 meters).

Fluid Properties Along Migration Route



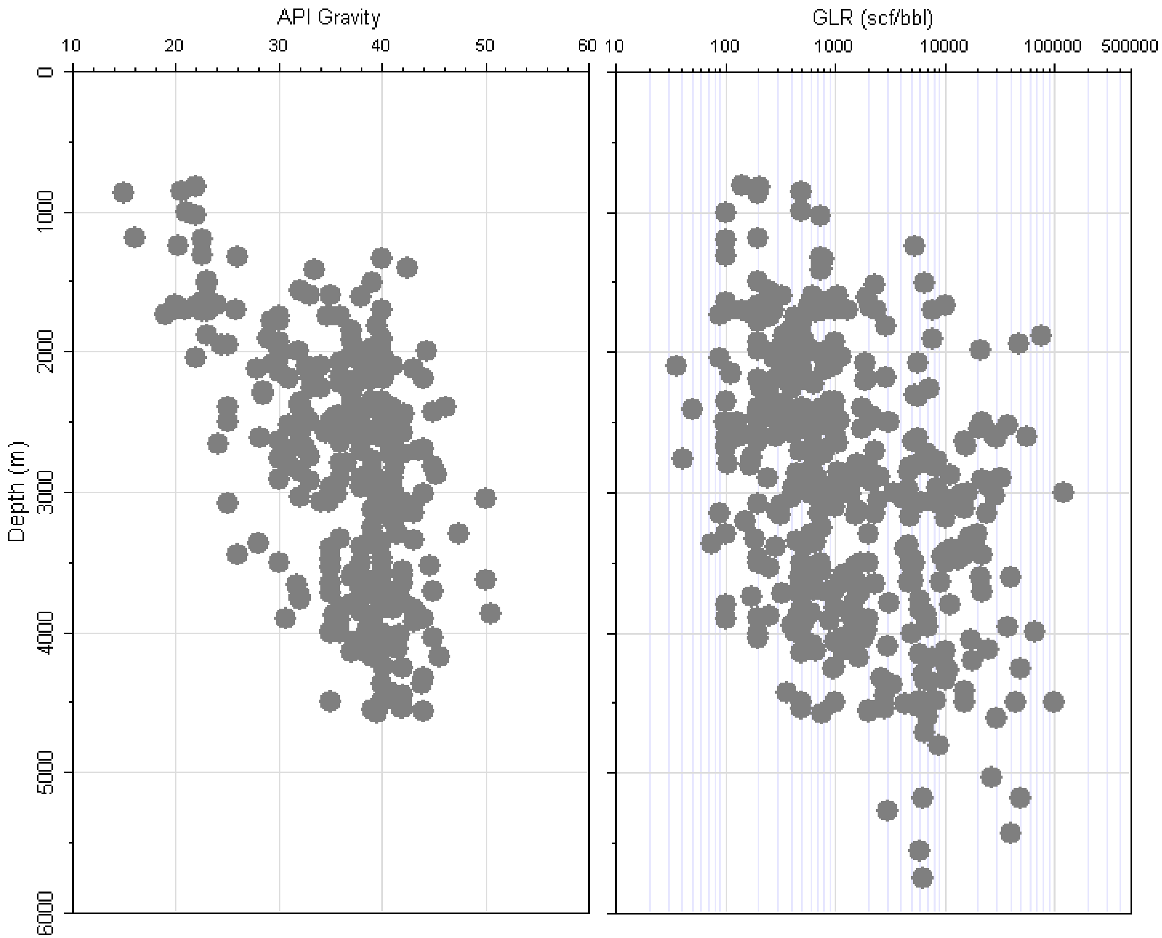
Central graben area, North Sea.

- ❑ Bulk fluid properties (API and GOR)and maturity of fluids will decrease toward the migration front.
- ❑ On the outer edges of basin, traps are charged more recently.
- ❑ Smaller traps near the kitchen more likely to be gas.
- ❑ Seismic mapping is not detailed enough to model the accumulations and volumes.

Can We Predict Fluid Properties?

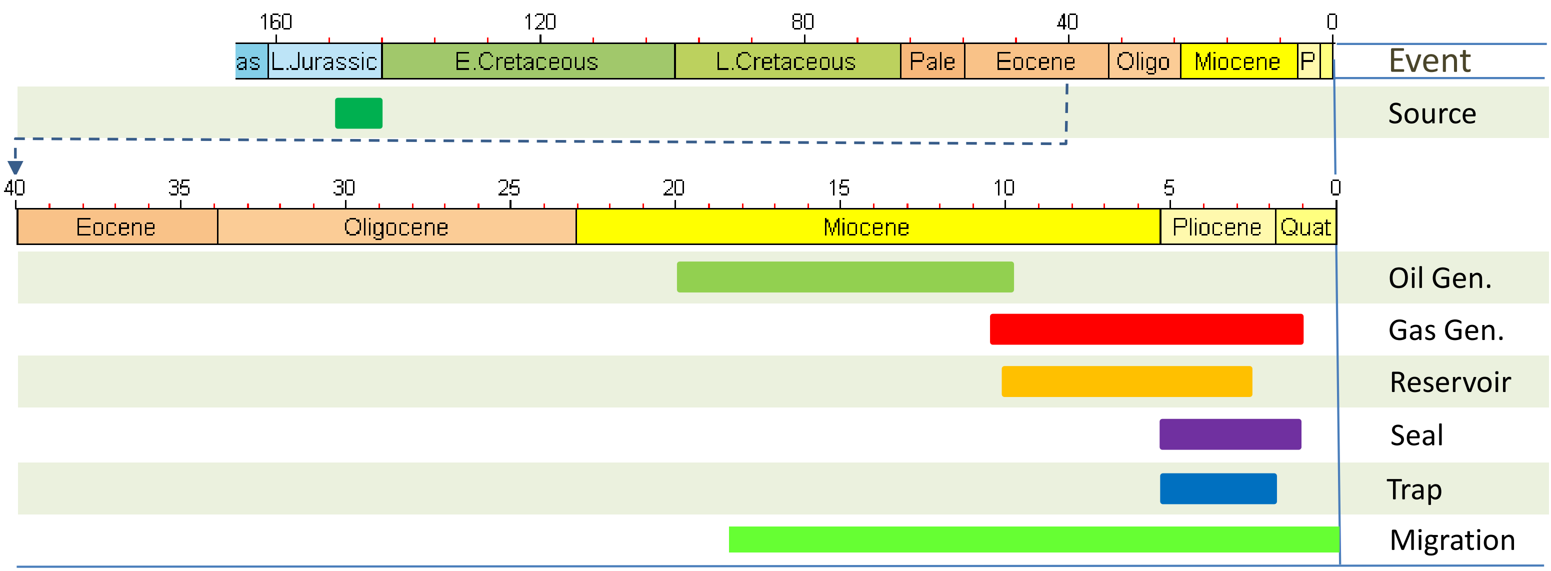
- Most traps can only hold a very small fraction of the volume expelled. The trapped fluid is less mature if the lag volume is large, and vice versa. Since the retained/lost volume is unknown, fluid property in a trap cannot be accurately predicted using a model.
- The overall trend along a migration path is predictable as shown in the previous slide, and by the Gussov example.
- Small traps near the kitchen more likely to be gas. Larger traps will have an more moderate properties as it captures fluids with a larger range of maturity.
- The uncertainty of migration lag/loss makes it fruitless to use complex compositional kinetics trying to predict fluid properties. A trap can contain gas even when the source rock makes mostly oil. The retained oil volume near and within the source will crack to more gas and increase the GOR of the system dramatically.
- We should stick to predicting and mapping such trends rather than trying to calculate the API and GOR for a prospect.

API and GOR trends in a basin



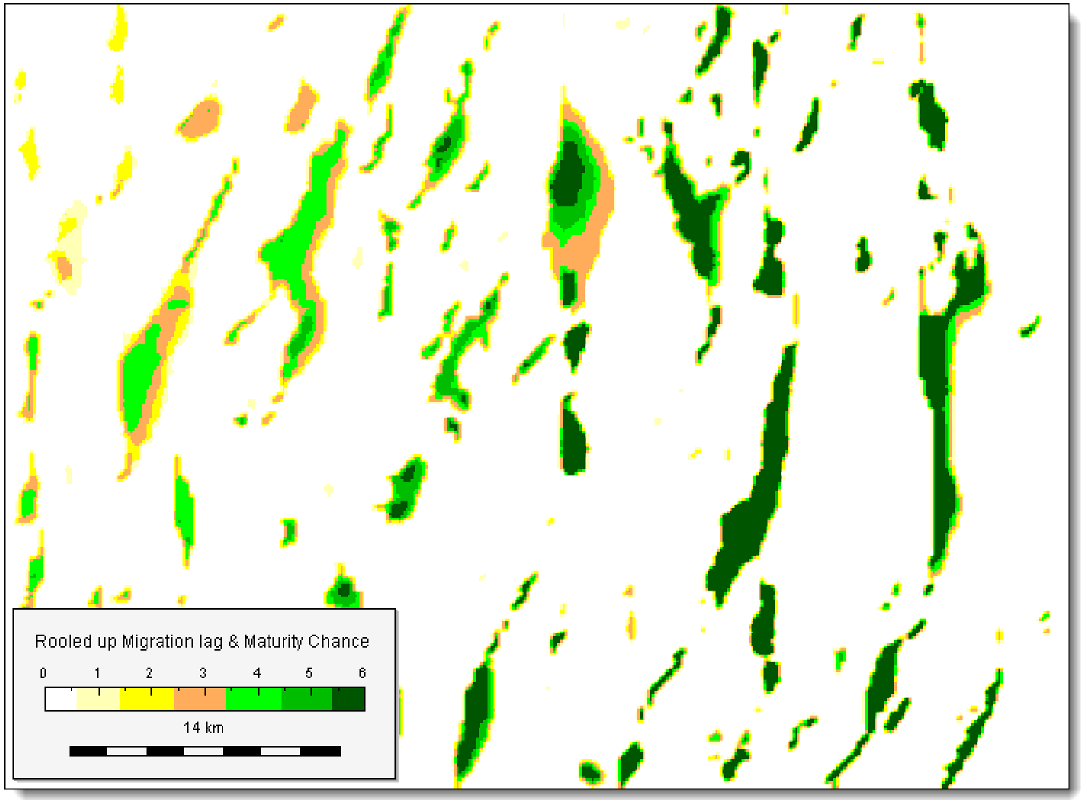
- Variation in fluid type and properties are complex in a basin.
- There is an overall tendency to have more oil, and lower GOR at shallower depth.
- This may be partly due to migration lag, particularly if migration is dominantly lateral.
- This can help us predict fluid up and down dip from known accumulations.

The Petroleum System Chart (Again)



- ❑ Migration and charging of traps will continue post generation.
- ❑ The youngest and up dip most traps are being charged most recently with fluids that was generated earliest.
- ❑ Simplistic timing analysis like this may lead to missed opportunities.

What to Do?



Because of unknowns (lag/loss volume and others), there are too many possibilities for any deterministic model to provide the right answer. One of the approaches we take is to run different scenarios of migration losses (lag) source rock potential. Combining the results to create “charge risk” map shown here using Trinity software developed by ZetaWare, Inc. The structure closures with darker green color indicate they are filled in more of the scenarios. Light Yellow to light green colored structures are less likely to receive charge.

Other Reasons for Late Charging

- Evolving maturation window from structure low to high.
- Natural kerogen conversion extends to higher maturity than most kinetics models indicate.
- Late contribution from secondary low quality high activation energy source rocks
- Volume increase from cracking of retained oil in source rock and deeper reservoirs.
- Loss of retention volume from compaction and diagenesis in deeper carrier/reservoirs
- Structural tilting of deeper carrier/reservoirs (remigration)
- Expansion of gas volumes and phase separation during uplift and erosion

Conclusion: If the basin is experiencing burial or structure deformation, migration is going on and traps are being charged present day.

Conclusions:

- Volume of hydrocarbons forming saturation in source rocks (think unconventional) and along migration paths, and retained in traps (sub seismic or larger) between our target and the source are the migration loss. It is that which causes the migration lag.
- The term "time lag" is used. But it is not related to the rate of migration. It is the time needed to generate this volume. The larger this volume is the longer it takes. The stronger the source rock is, the shorter it takes.
- The size of this volume (migration loss) will determine when and whether up dip traps will receive charge, and type and properties (important?) of charged fluids if any.
- The lost/retained volume cannot be determined on seismic so we need to engage scenario testing, and use geological analogs.
- There are many other factors that cause continued migration
- Timing is not an important factor in exploration risk.