Predicting Tilted Fluid Contacts: Case Study from a Carbonate Reservoir in NW Oman*

Mohammed Al Kindi[1] and Ibrahim Al Ismaili[1]

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[1]Vision Advanced Petroleum Solutions, Muscat, Oman (malkindi@gmail.com & ibrahim.ismaili@gmail.com)

Abstract

Predicting the geometries of current and paleo-fluid contacts is critical for field development and reserve estimations. In low-permeability carbonate reservoirs that underwent significant deformation after the main hydrocarbon charging phase, millions of years might be required before fluid contacts regain flat levels. This article presents a thorough analysis of the trap geometry and its evolution during and after hydrocarbon charging which has affected the current distribution of hydrocarbons in the field. Our study shows that the integration of reservoir evolution models, petrophysical logs and production data can help estimate the location of current mobile hydrocarbons and define the transition zone in which high water rates are often coproduced with hydrocarbon and where imbibition saturation curves should be used to estimate saturations. The results also provide better insights on the locations of spill points and the future appraisal and development plans. The results from this study could be applicable to many fields in the region, where significant structuration or deformation of the reservoir took place after the main charge, and hence the paleo-structure actually is the key to understand the limit of a field and therefore it controls its development.

Main Results

- The big closure of the structure was formed during Late Cretaceous.
- It was charged with oil down or close to spill point during Early Tertiary.
- The SW boundary fault was reactivated after charge (during Early Tertiary).
- The oil from the Lower Shuaiba was breached either to Upper Shuaiba or Shammar.
- The NE structure maintained an OWC close to -1289 tvdss, which represents the spill point of a 4-way dip closure in this part of the field.
- During Late Tertiary (about 10 to 5 million years ago), the NE structure was tilted by about 7.5 to 8 m every 1 km to NE>
- Therefore the present OWC in the NE is still under equilibrium below around 1280 tvdss (imbibition phase).
- Mobile oil could still be produced below -1289 tvdss in the NE part of the NE field, as evident from well 5. This highlights the opportunity that exists in the NE part of the field.

Conclusions

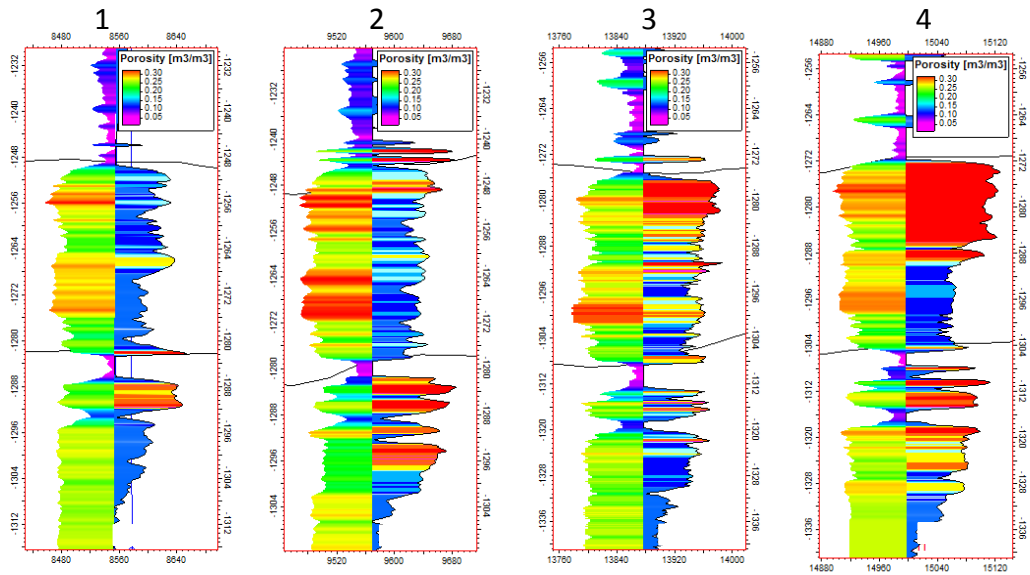
The NE-SW fold structure and NW-SE faults, which were originally formed during the Cretaceous, underwent significant re-structuration (tilting of structure and reactivation at different degrees of faults) after the oil charge during Tertiary, caused by a NE-SW compression, which also resulted in the formation of NE-SW faults. Some of the Late Cretaceous faults were reactivated and affected the Tertiary strata, causing the oil to partly re-migrate to shallow reservoirs. The originally flat oil-water-contact was, therefore, tilted in the field during Late Tertiary to Early Quaternary. Evidence from the dynamic behaviour of the field and its petrophysical logs and production data indicate that the current oil water contact still has not maintained a flat level.

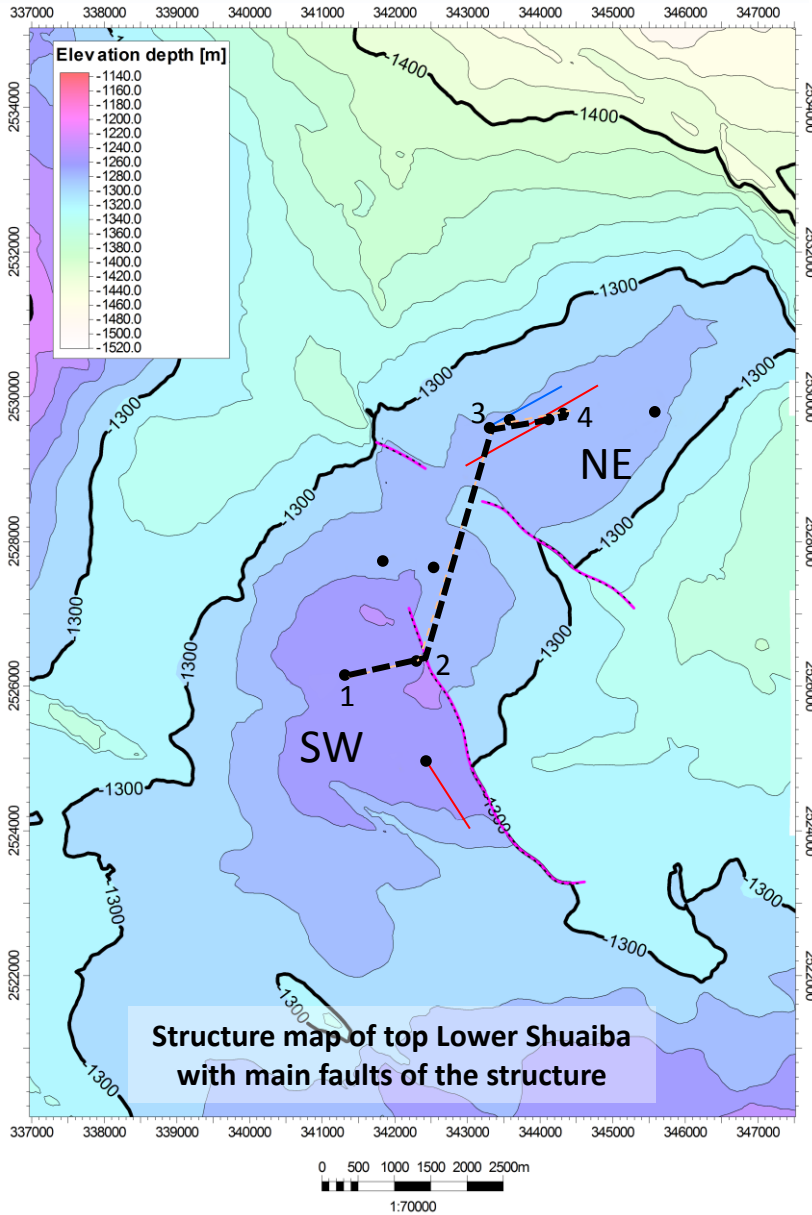
Acknowledgments

The work was of an updated field development Plan conducted by Vision Advanced Petroleum Solution L.L.C. for Petroleum Development Oman L.L.C. We would like to thank the Ministry of Oil and Gas and Petroleum Development Oman for their support and permission to present this work.

Geological Setting

- The structure is divided to two segments, NE & SW.
- The segments are separated by a bisecting system of NW-SE trans-tensional faults that form a graben between the segments.
- NE segment is partly flanked by bounding fault from the southern side, whereas the SW segment is cut by a fault in the crest.
- Reservoir properties of Lower Shuaiba are similar in both segments.
- The good saturation above the predicted contact is missing in SW.

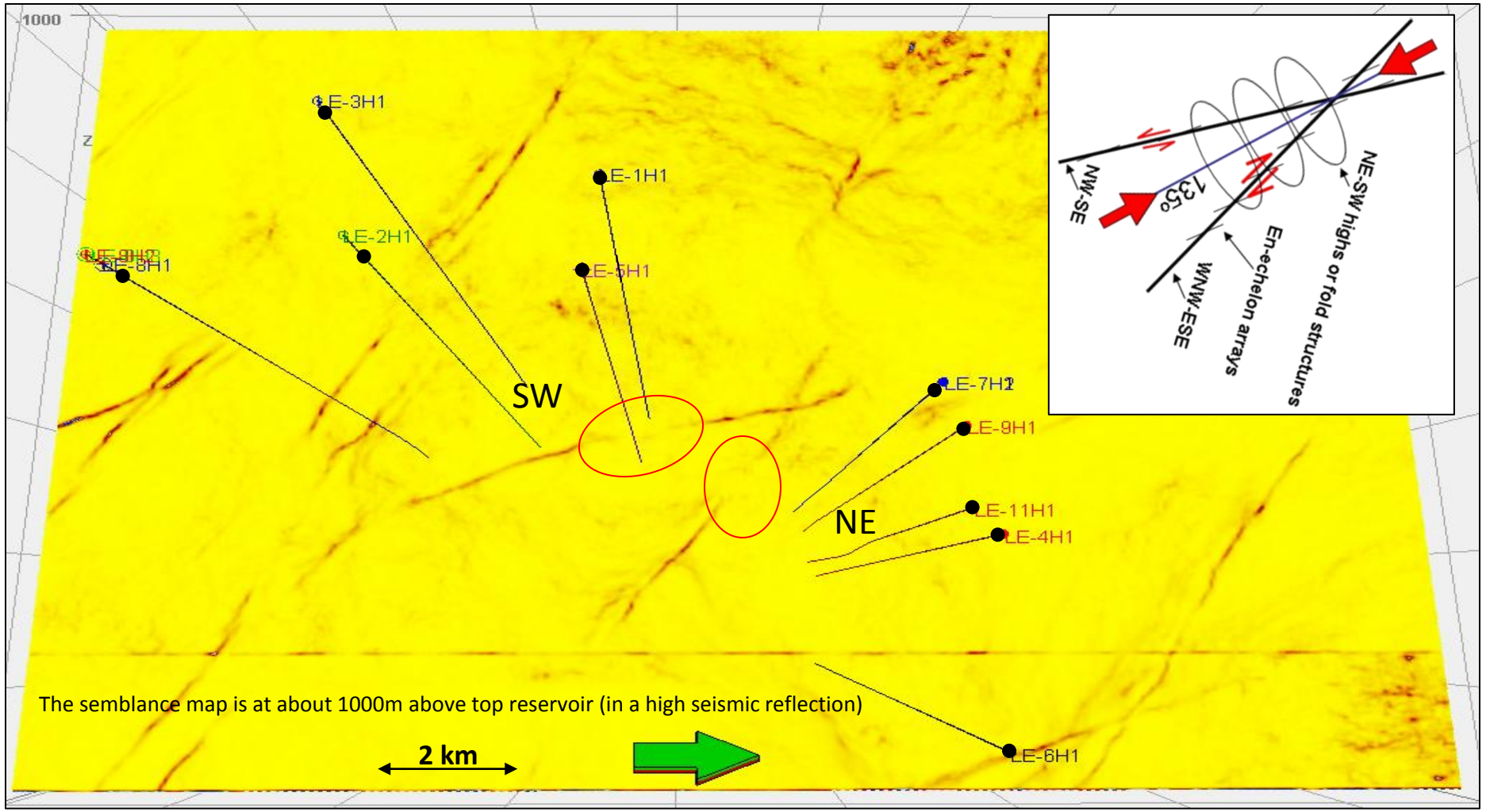




Structure map of top Lower Shuaiba with main faults of the structure

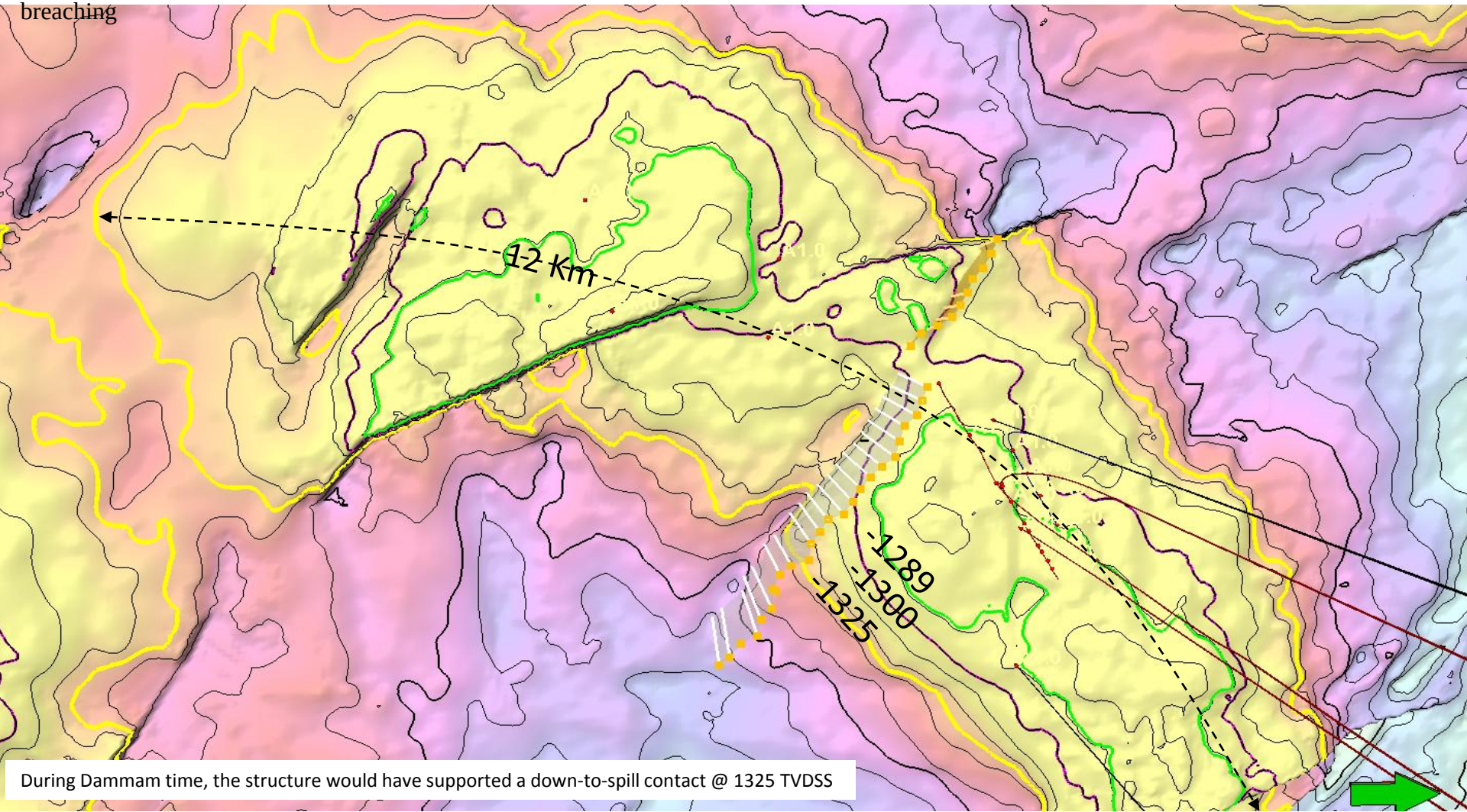
Summary of previous work

A semblance slice at the field area shows a gap in the boundary fault of the NE segment, therefore excluding the possibility of a 3-way dip closure. Note the north sign on the structure map. Likewise, the fault bounding the SW structure is most likely not continuous. These NW-SE en-echelon faults and NE-SW low-laying anticlines formed during Late Cretaceous as a result of a NW-SE compressional event. As the faults grew larger, the individual segments connected together, but in most cases these connected fault systems do not continue for more than 5 km.



Summary of previous work

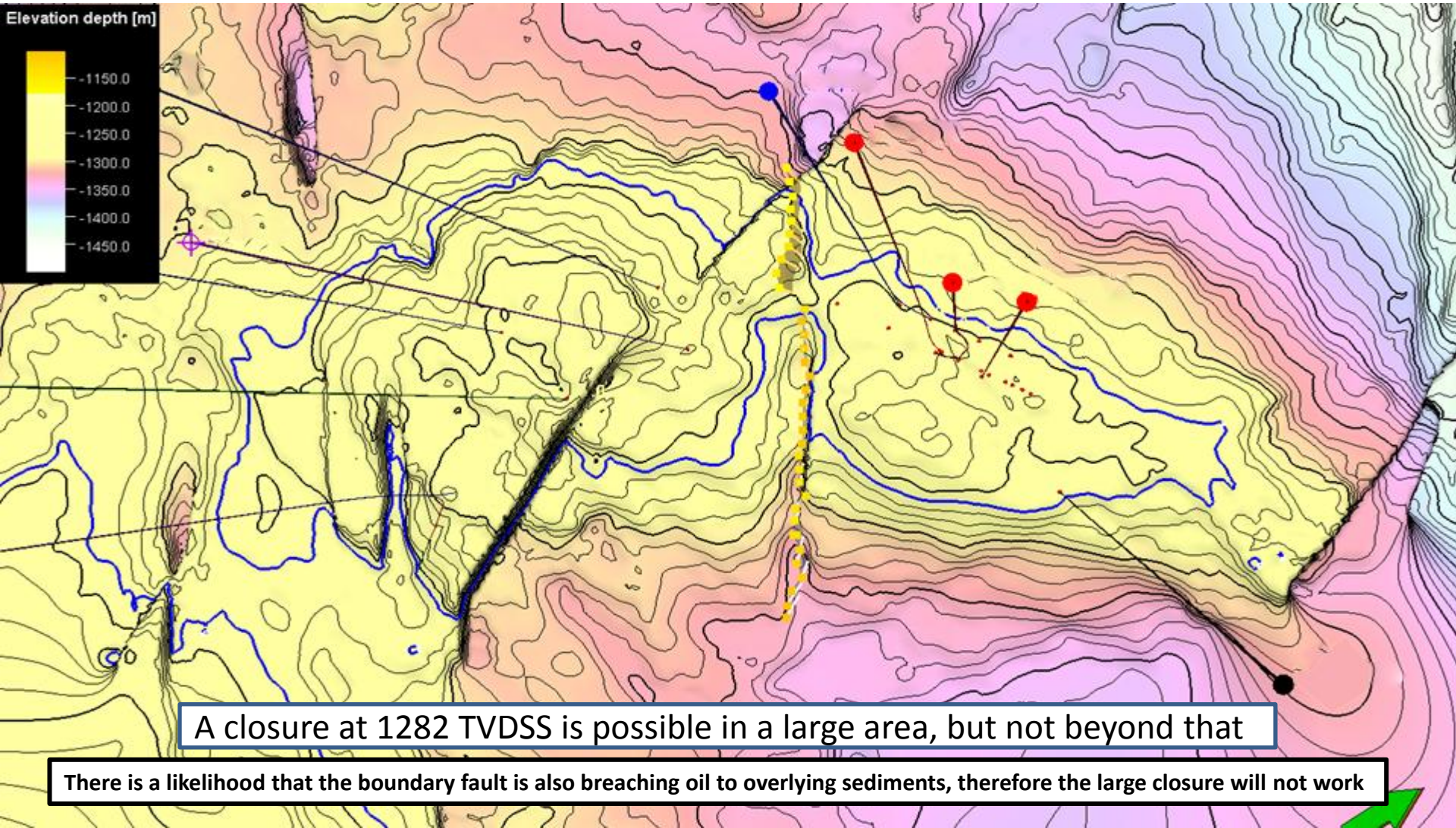
This is a depth structure map of top Lower Shuaiba reservoir in the field during Early Tertiary, flattened at the time when the main oil charge most likely occurred. The map shows that the structure had a regional spill point at -1235 tvdss and the NE segment has a 4-way dip closure down to -1289 tvdss. The actual numbers are possibly not precise because the reference level for flattening the Late Tertiary tilting is not known. But, they should give a very good idea about where the paleo OWCs in both segments of the field were before tilting and possibly breaching



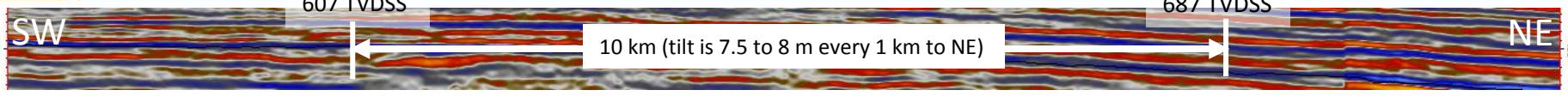
During Dammam time, the structure would have supported a down-to-spill contact @ 1325 TVDSS

The top Lower Shuaiba today

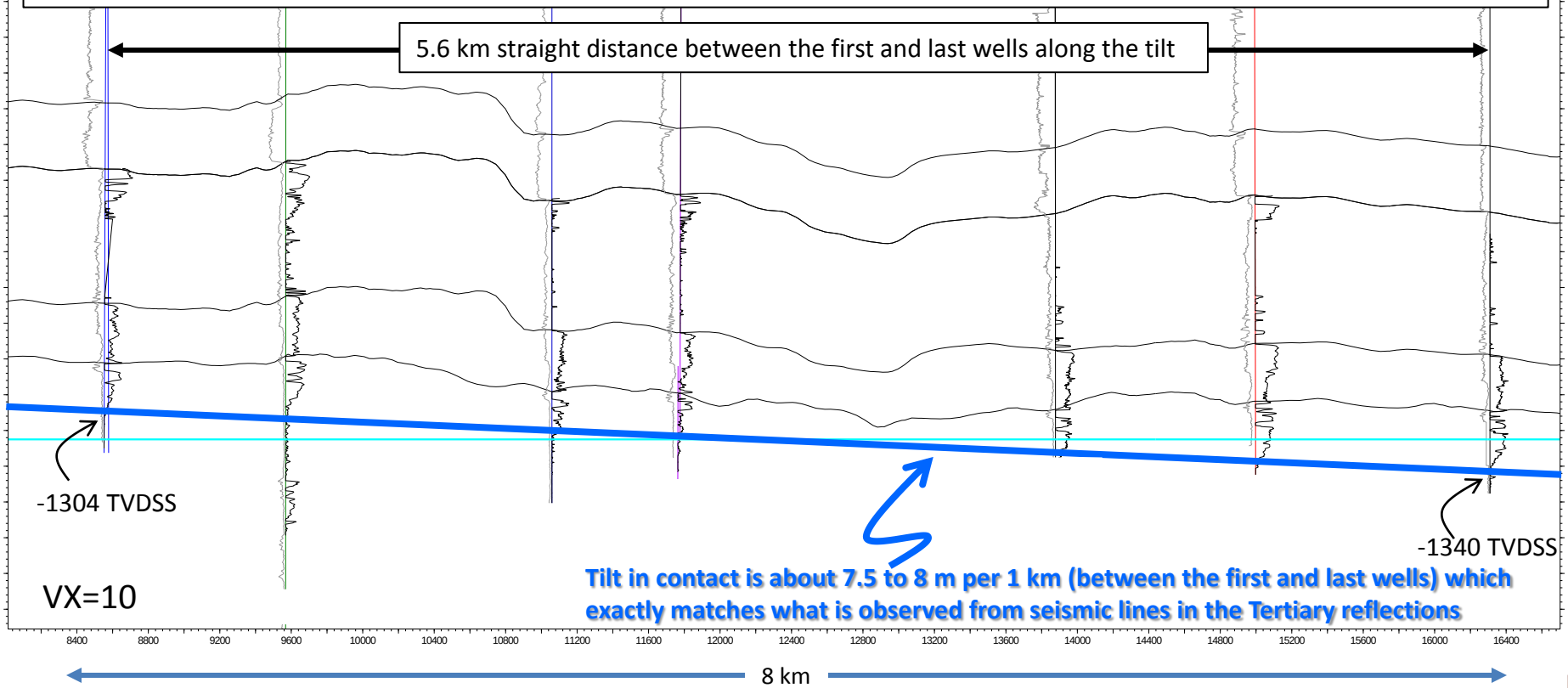
When we compare top Shuaiba at the time of charge to top Shuaiba today, we would conclude that the field has significantly changed trap geometry after it was charged with oil. Today, a large closure would only be possible at 1282 TVDSS and if any of the bisecting faults is breached, then we will lose oil to the overlying sediments.



Tilted Palaeo-Contact

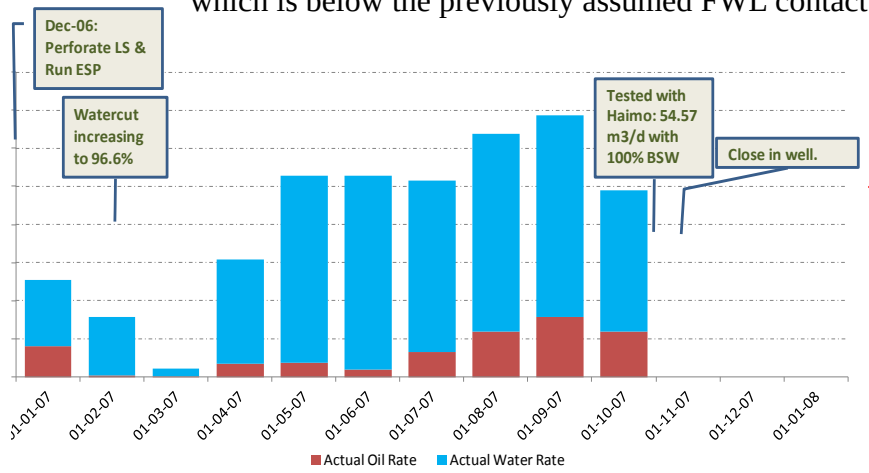


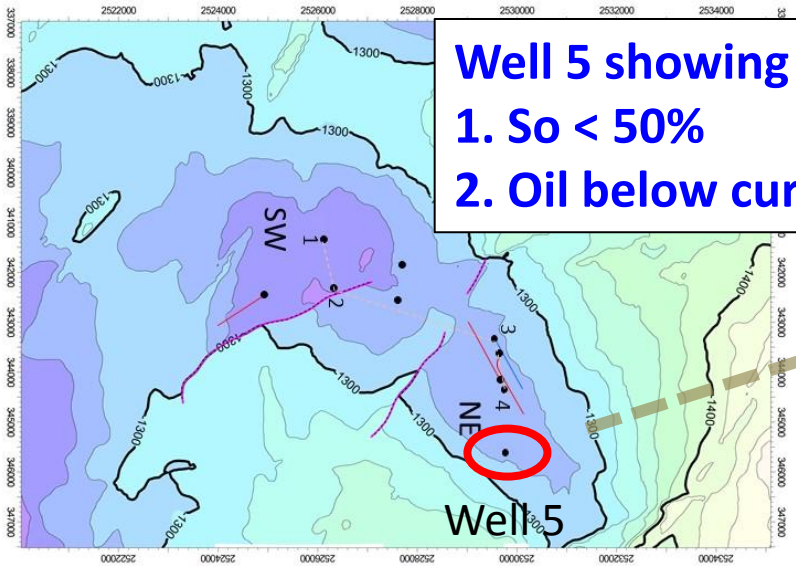
- The analysis of the saturation logs across the wells from the SW side to NW side suggest that that the oil-down-to of the most likely residual oil across the whole is indeed tilted, from around -1340 tvdss to -1304 tvdss (dark blue line) around the line of -1325 tvdss (light blue line). The tilt from logs matches very well the observed tilt from seismic (about 7.5 m every 1 km to NE), indicating that the paleo-contact is indeed tilted.
- In fact, it is well possible, as shown from the logs, that the current mobile OWC in the NW-segment is also currently tilted and oil is under imbibition/equilibrium on the northern part.



Well 5

Well number 5 is producing from a perforation zone which is below the previously assumed FWL contact.

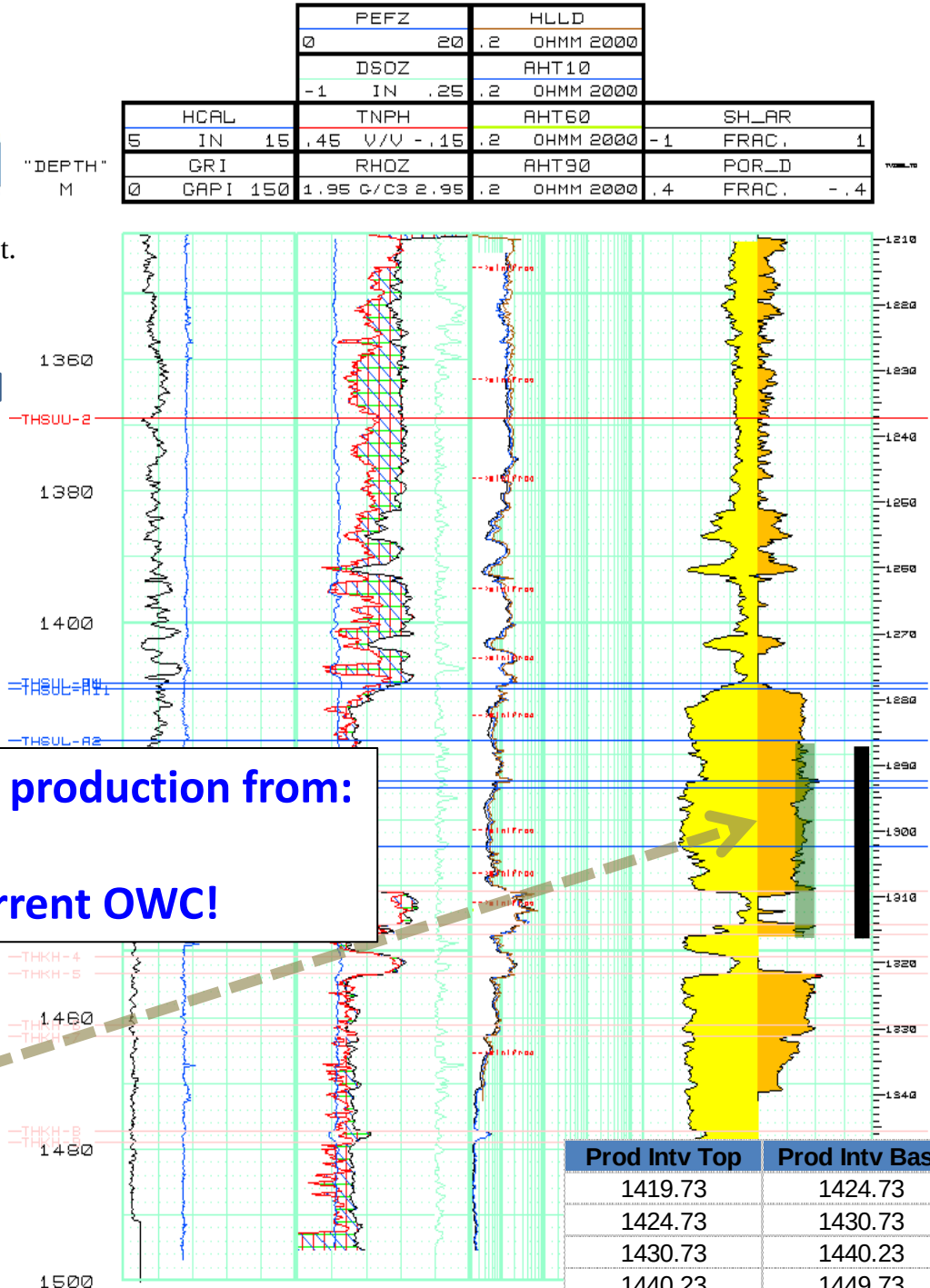




Well 5 showing production from:

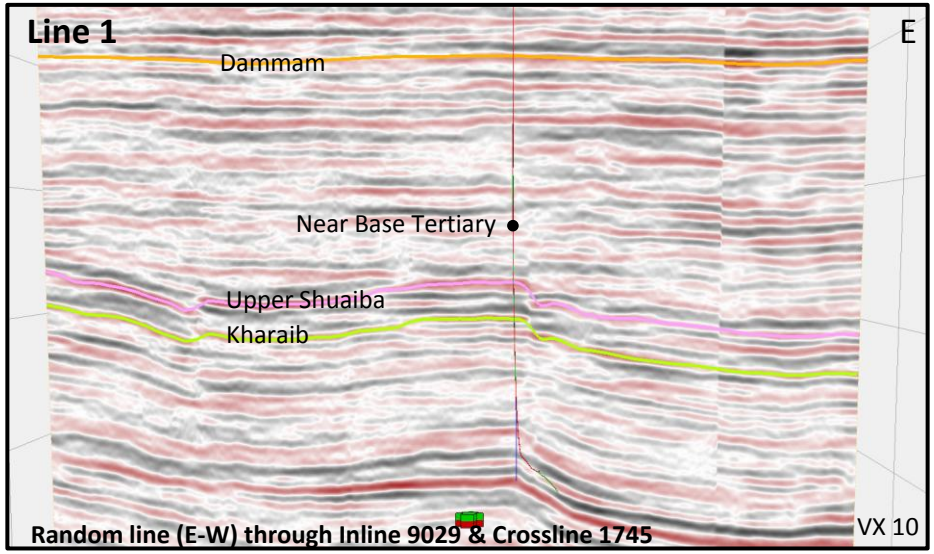
1. So < 50%

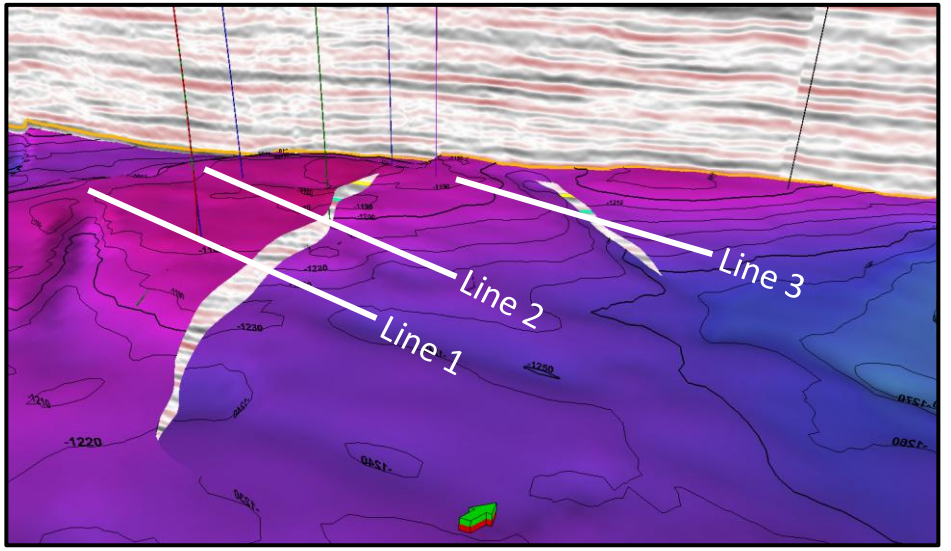
2. Oil below current OWC!

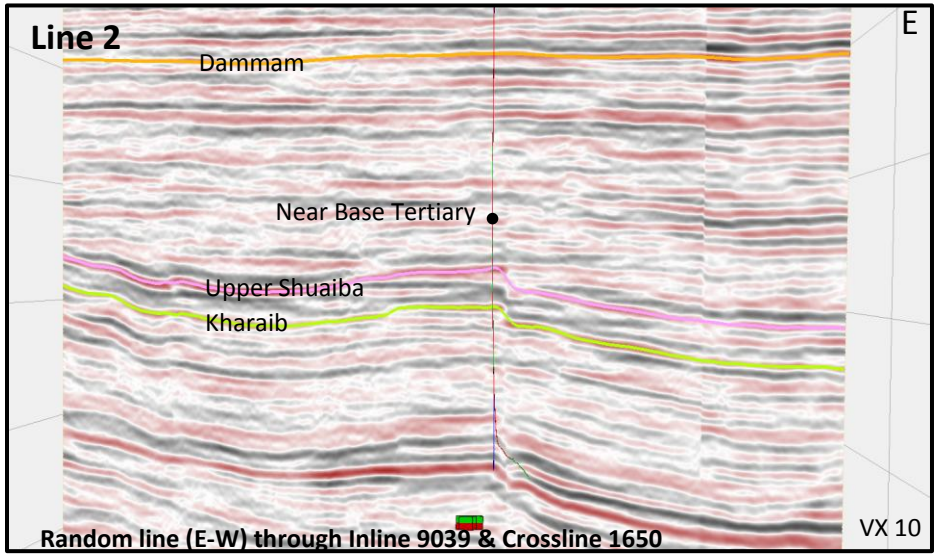


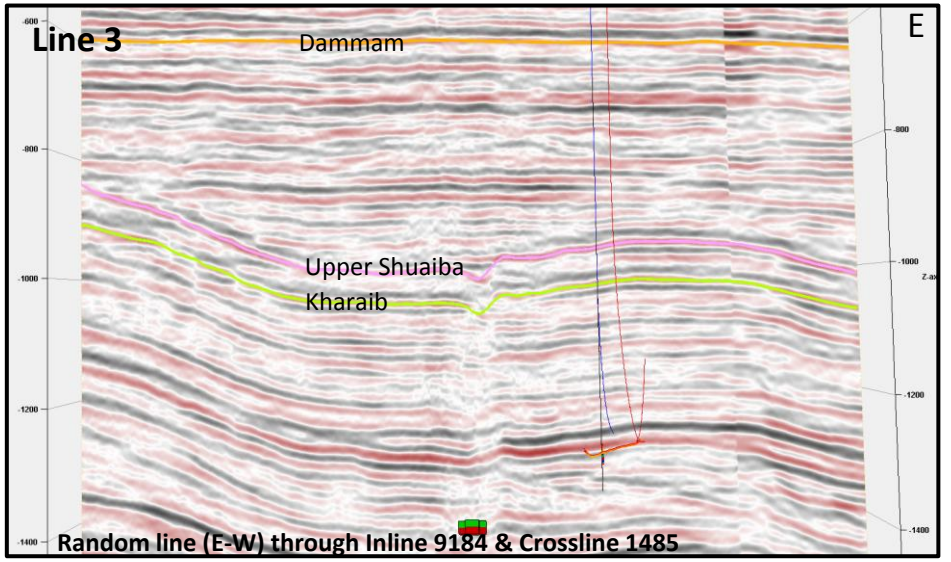
Prod Intv Top	Prod Intv Base
1419.73	1424.73
1424.73	1430.73
1430.73	1440.23
1440.23	1449.73

Towards building a concept model: Nature of the boundary faults



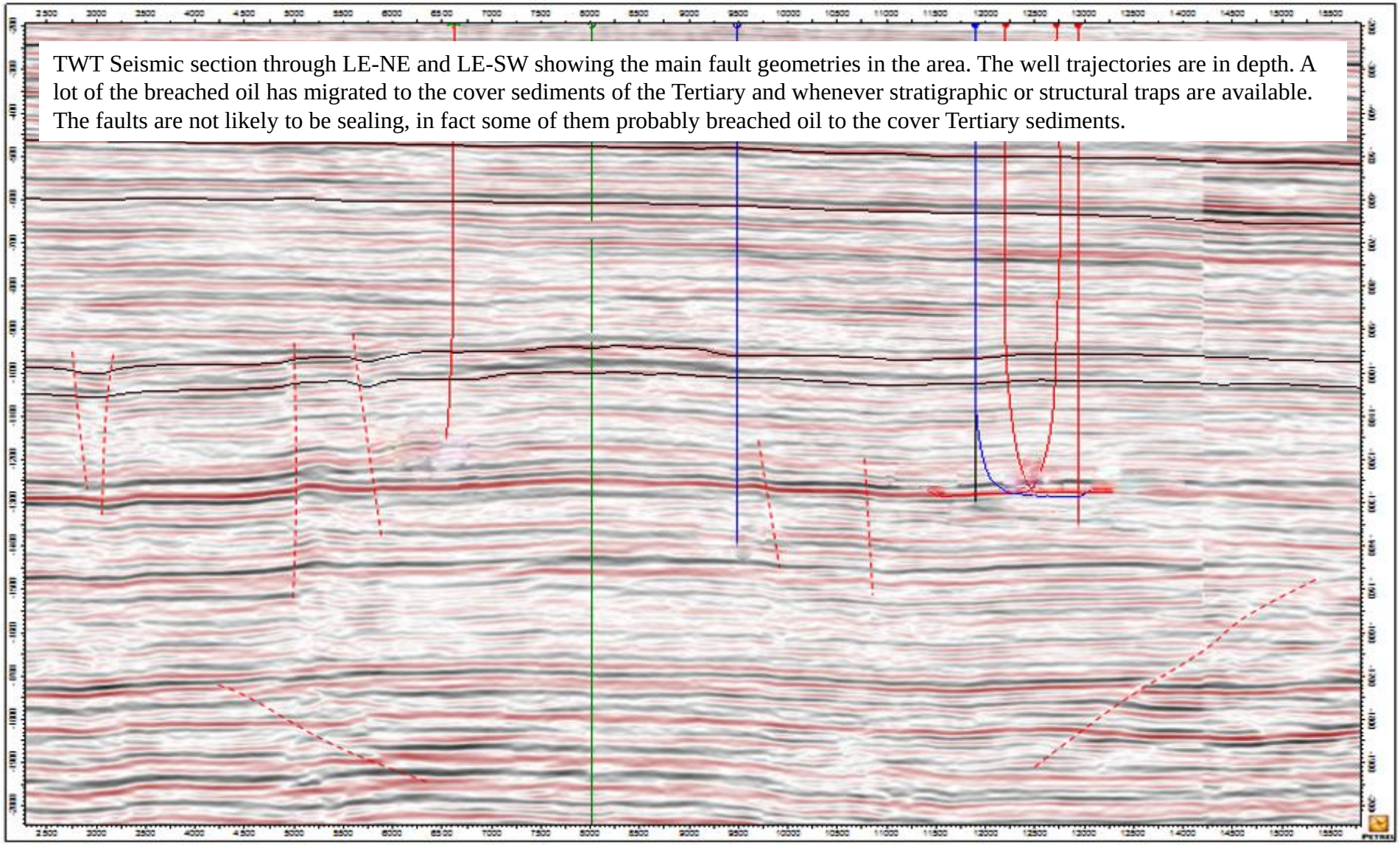






A number of time seismic intersections through the boundary faults of the SW segment (Lines 1 and 2) and the NE segment (line-3). The bounding fault in SW is likely to continue beyond base Tertiary, this is not the case for the boundary faults of the NE segment.

Towards building a concept model…overall setting



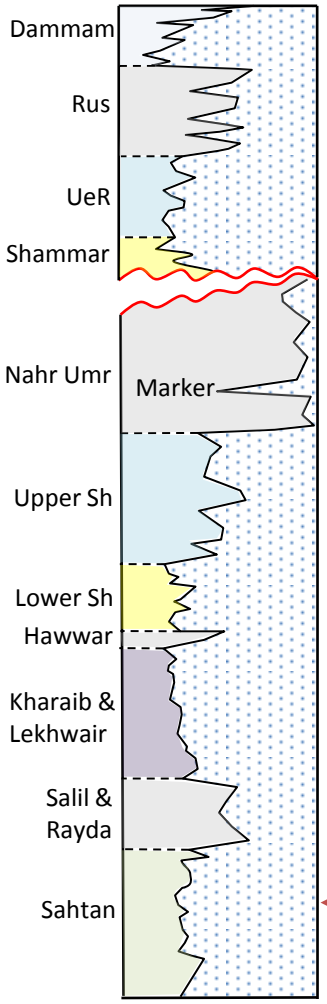
TWT Seismic section through LE-NE and LE-SW showing the main fault geometries in the area. The well trajectories are in depth. A lot of the breached oil has migrated to the cover sediments of the Tertiary and whenever stratigraphic or structural traps are available. The faults are not likely to be sealing, in fact some of them probably breached oil to the cover Tertiary sediments.

Summary of observations

- Evidence of a paleo-contact that was tilted and paleo oil
- Boundary faults are bisecting the crest of SW and the flank of NE
- NE wells contains clear oil column with approx. 50% So (oil saturation), which is not seen on SW wells
- There is a good match between interpreted So & SHF (Saturation Height Function) in NE but not in SW
- Low saturation in NE was produced in well 5, however the production was low
- The SW structure was tested at well 1, but it tested only water, although the test was reported inconclusive
- Expected production from crestal SW wells is similar or lower than well 5 (not economically viable to drill SW)

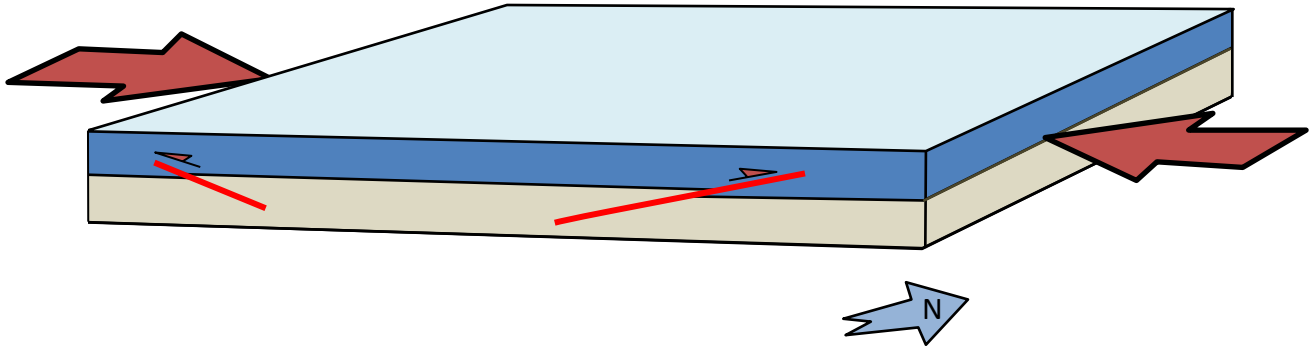
Pre-Cretaceous

Simplified GR response



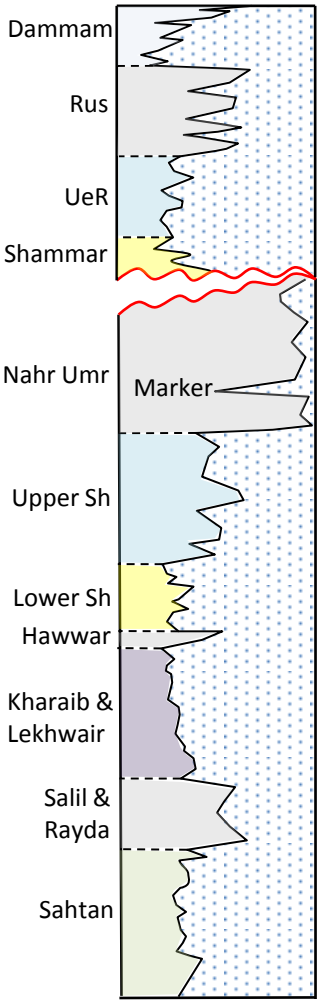
Jurassic (Sahtan Group)

It is not clear from the given data whether this event was extensional (inverted normal faults) or compressional. The shallow dip of the reverse faults suggest that they formed as reverse faults.



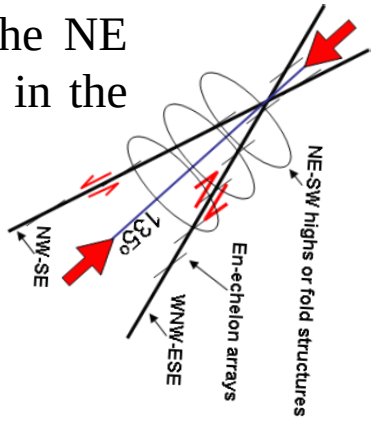
End of Cretaceous

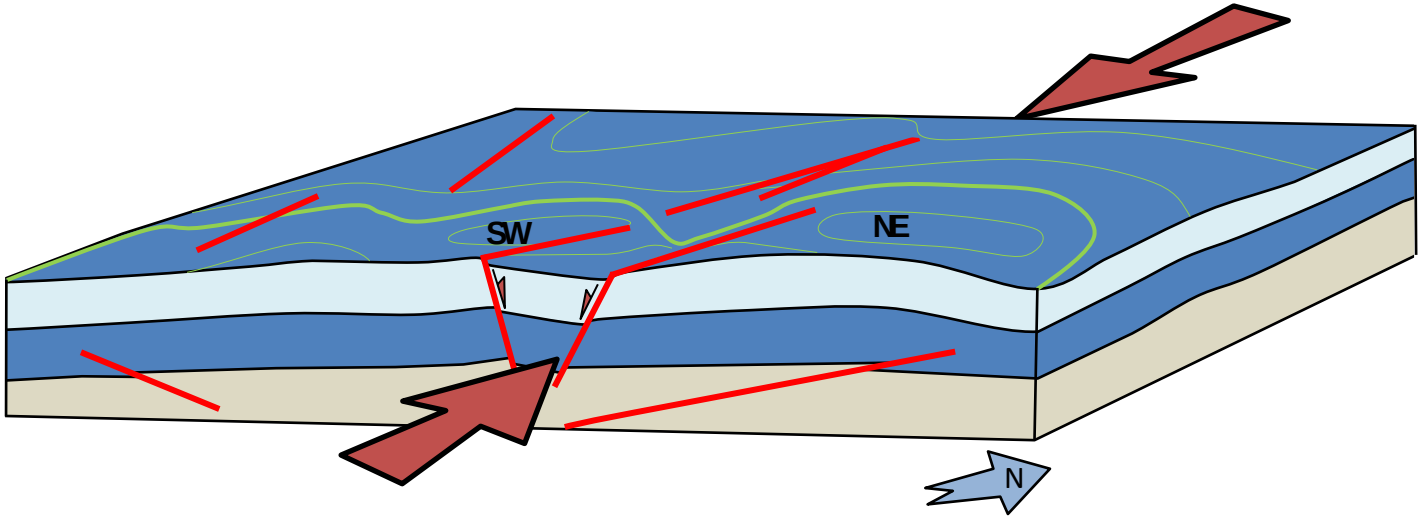
Simplified GR response



NW-SE compression in Late Cretaceous (around Santonian-Campanian) led to the formation of anticlinal and fault closures. The interaction between these closures could be challenging particularly with tilted contacts. Unlike the NE structure, the SW fold closure is cut by a major fault in the crestal part.

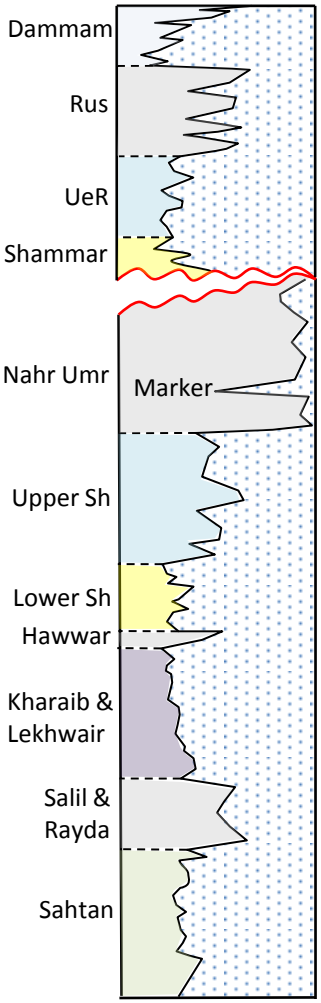
Late Cretaceous (Aruma Group)





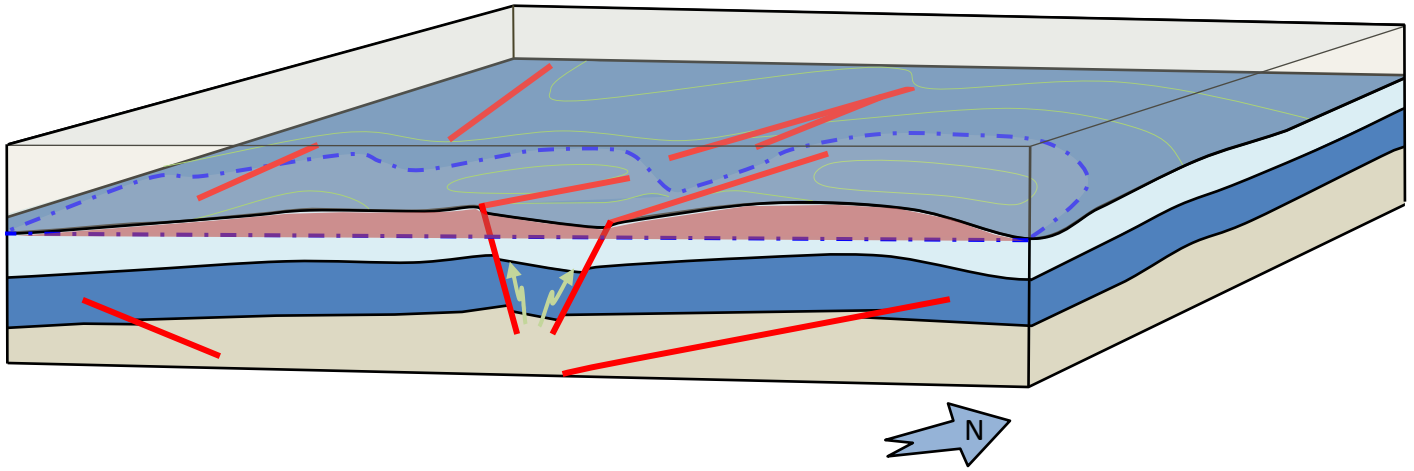
Charging in Early Tertiary

Simplified GR response



The charging of the structure possibly occurred in Early Tertiary or even Late Cretaceous, mainly from Huqf Oil that was expelled from source rocks and migrated to motel structures a long time ago, before re-migrating upward through the main faults in the area.

Early Tertiary (Charging)

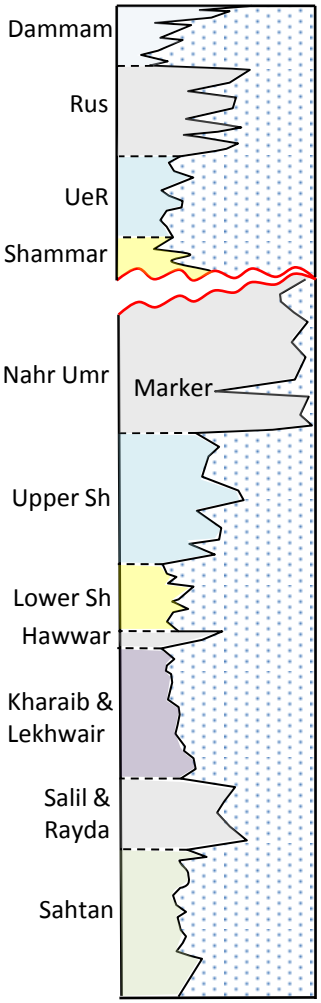


Most likely the two segments of the field were in communication across the entire structure as none of the faults are completely bisecting it.

NE-SW Compression in Tertiary (Scenario 1)

A likely scenario given the continuity of the boundary fault to Tertiary as seen from seismic data, and the likely absence of mobile oil from petrophysical logs.

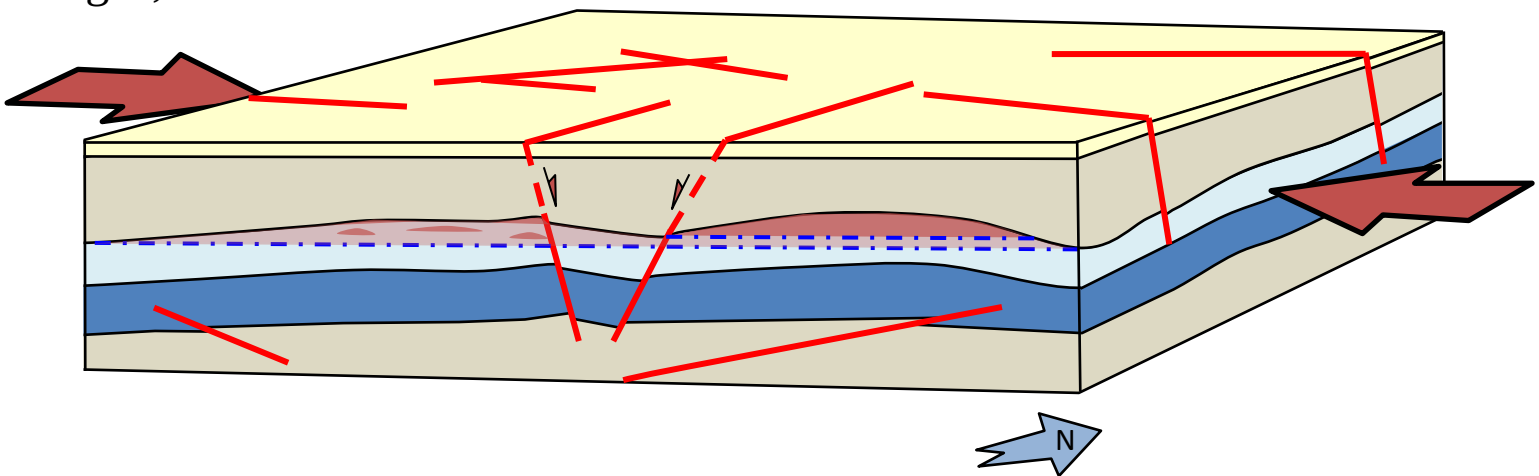
Simplified GR response



Tertiary (Compression)

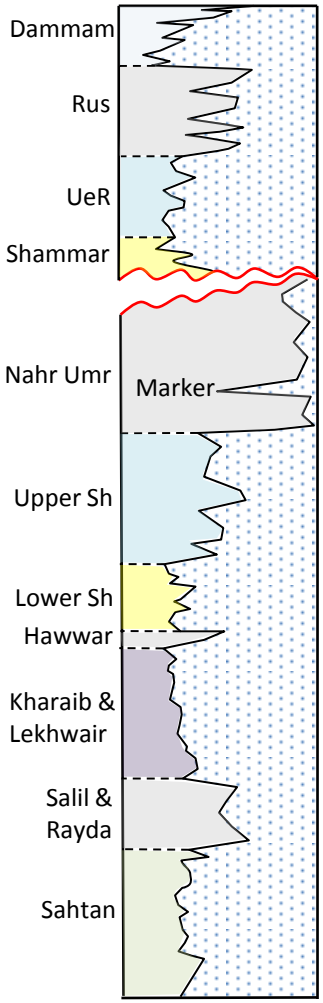
The structure underwent significant re-structuration after the oil charge during Tertiary, caused by a NE-SW compression which resulted in the formation of NE-SW faults. Some of the Late Cetaceous faults were reactivated and affected the Tertiary strata.

Did these fault cause upward breaching of oil from the traps of Lower Shuaiba to Upper Shuaiba or Shammar? Were minor pockets of oil retained in the SW because of capillarity, wettability, compartmentalization, local highs, etc?!



NE-SW Compression in Tertiary (Scenario 2)

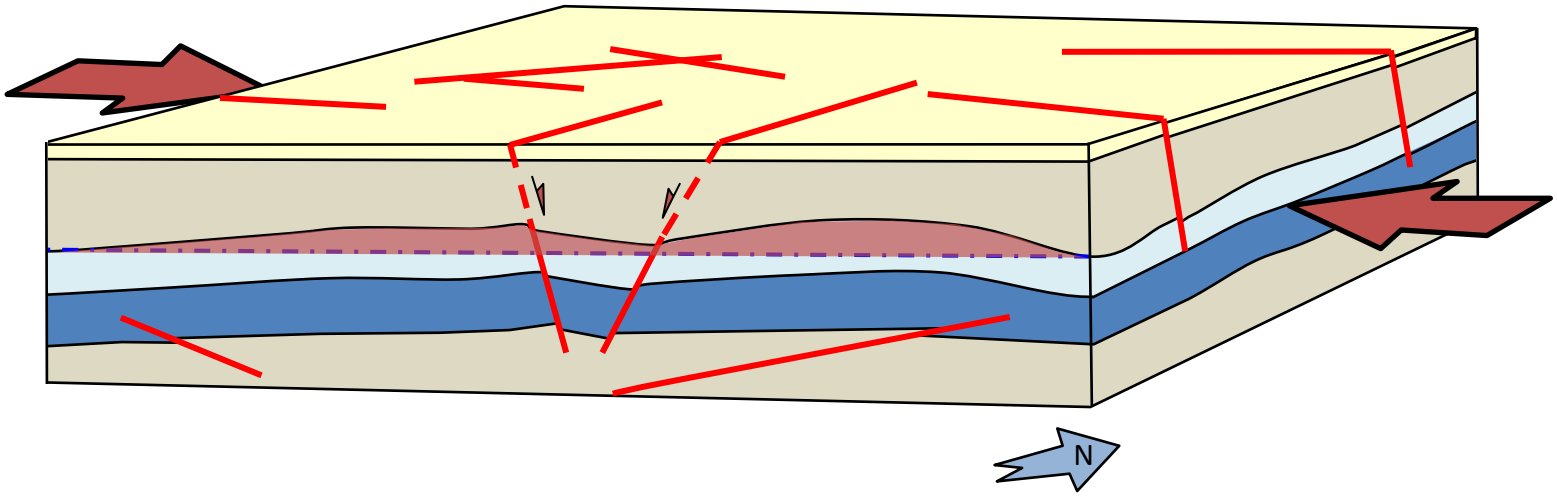
Simplified GR response



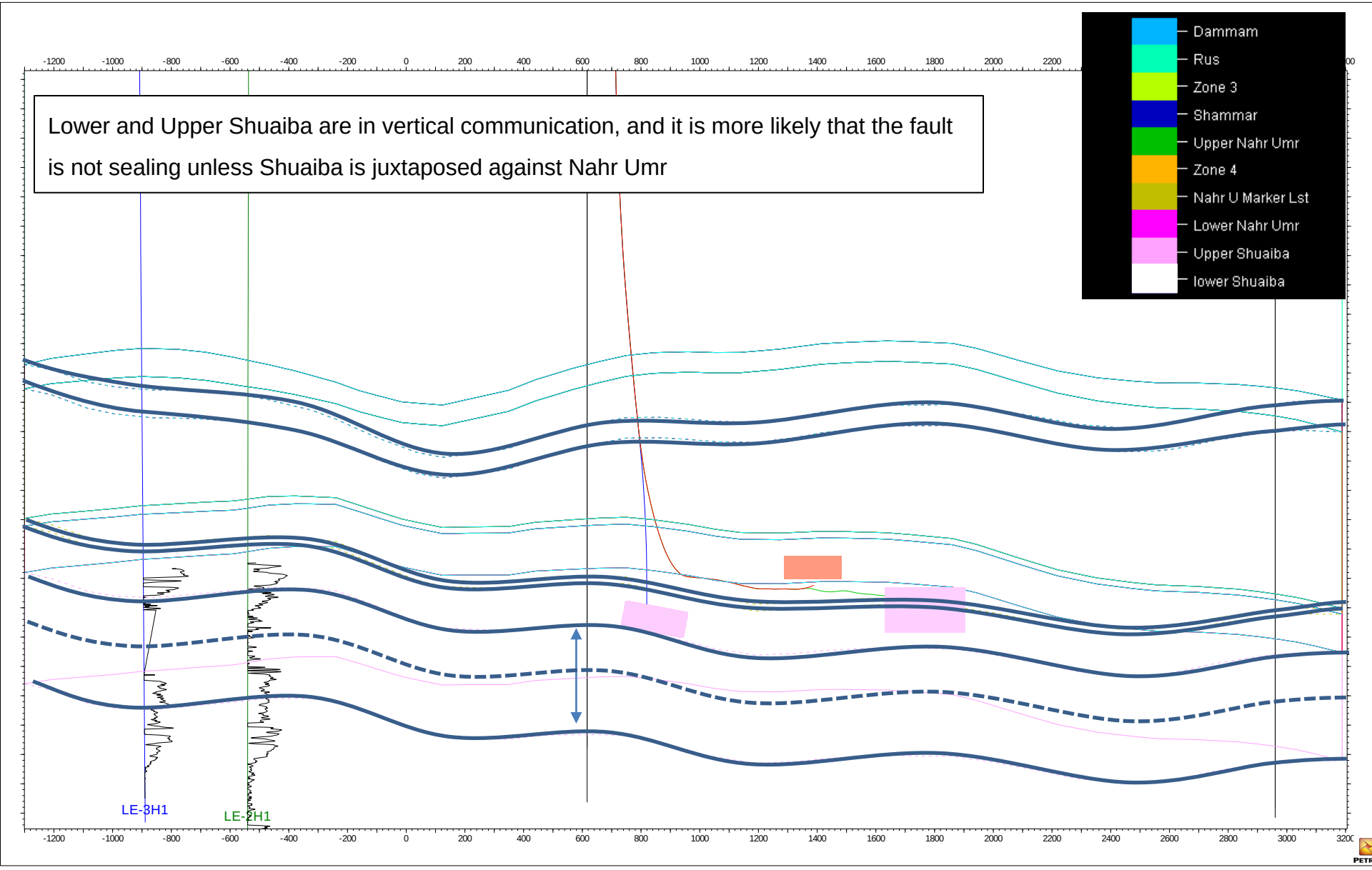
Tertiary (Compression)

The structure underwent significant re-structuration after the oil charge during Tertiary, caused by a NE-SW compression which resulted in the formation of NE-SW faults. Some of the Late Cetaceous faults were reactivated and affected the Tertiary strata.

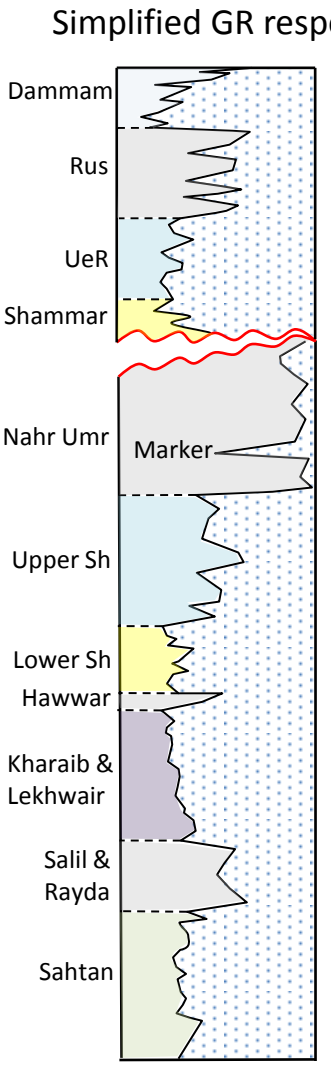
Did these fault cause upward migration of oil from the traps of Lower Shuaiba to Upper Shuaiba or Shammar?



Alan Diagram

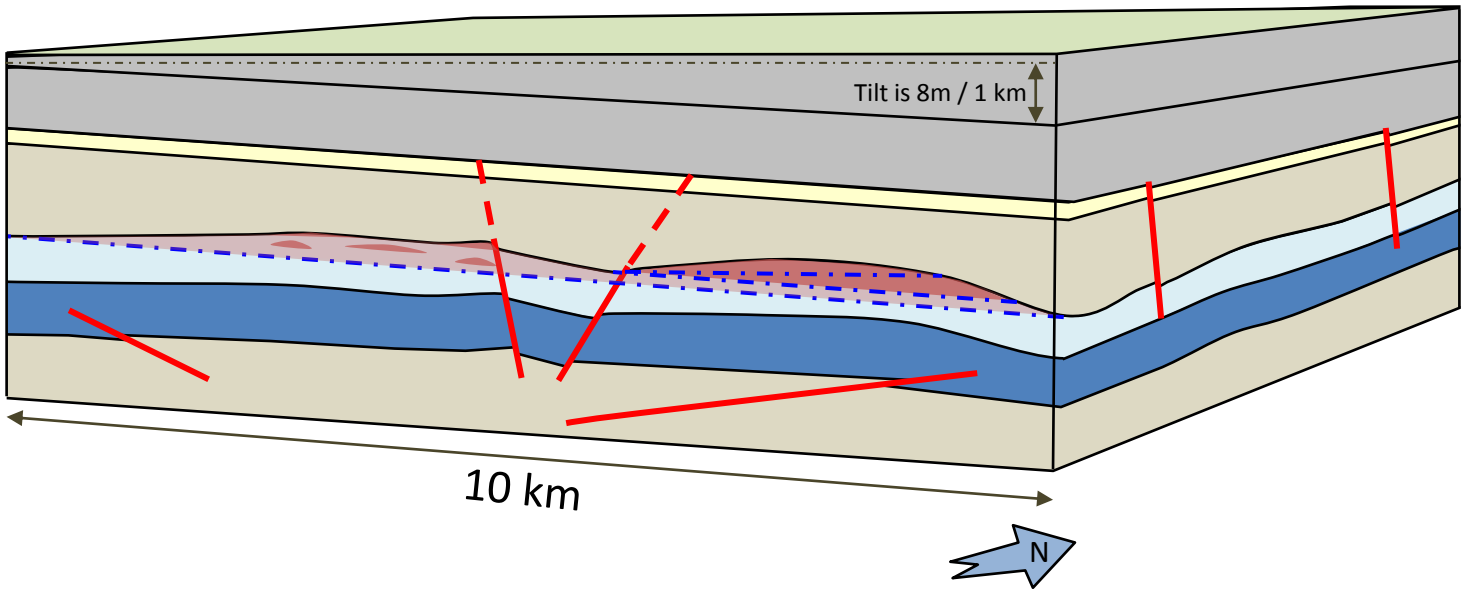


Tilting

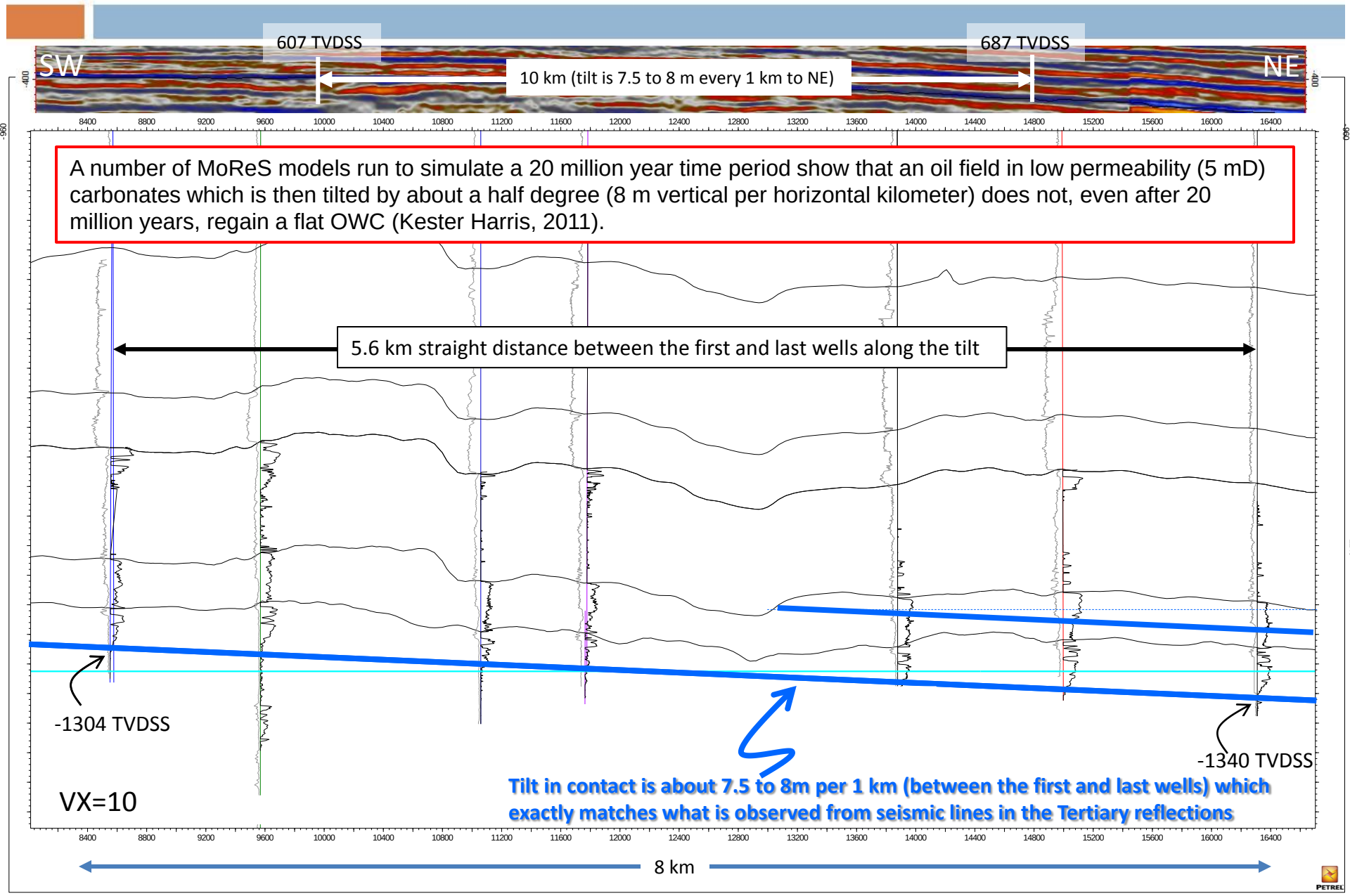


Tilting (Miocene)

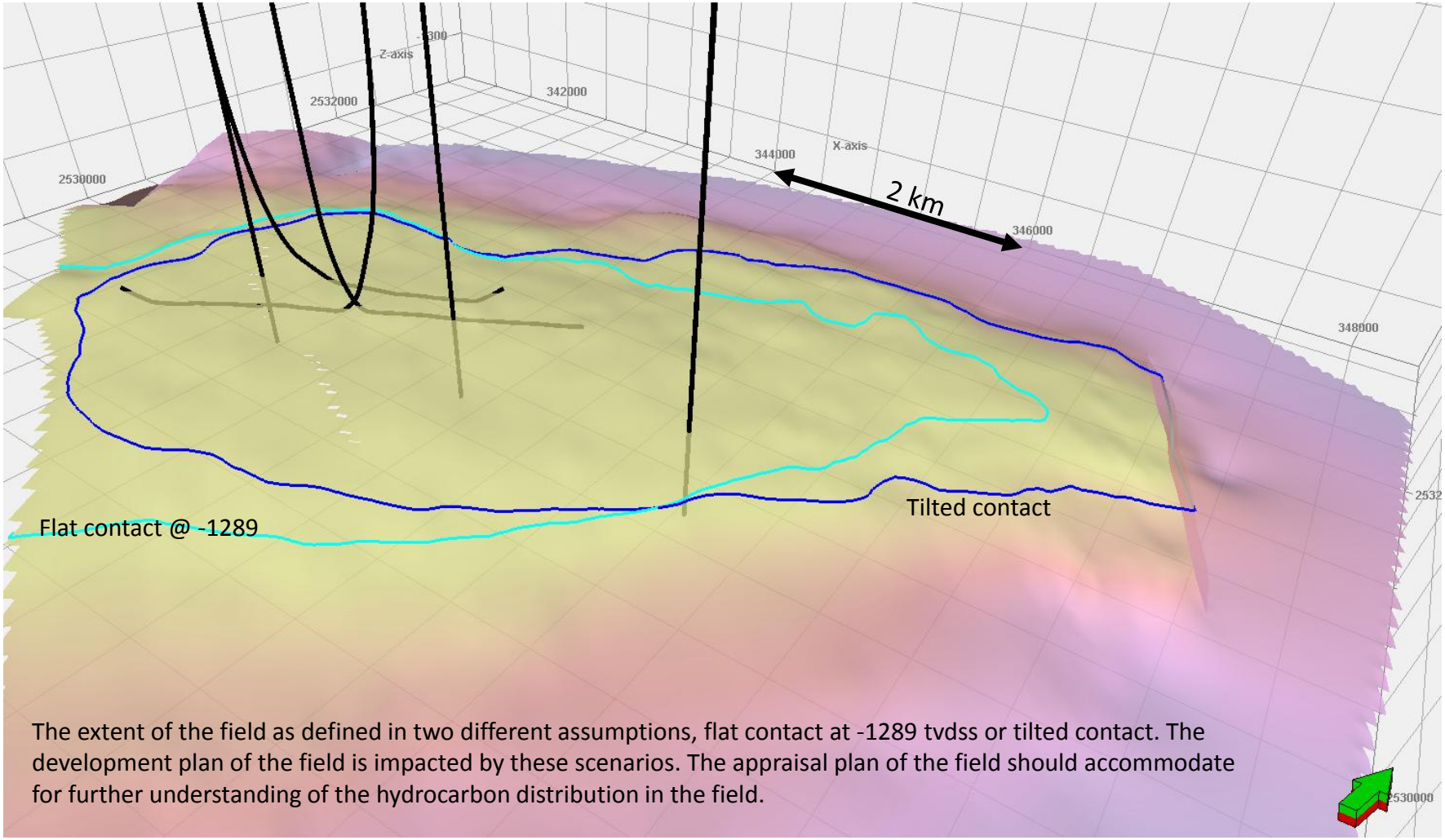
Regional tilting down to NE occurred during Late Tertiary, most likely during Miocene. It affected the regional paleo contact as well, as evident from the petrophysical logs. However, the question remains: is the current FWL in the NE structure tilted or flat? For example, some nearby structures were tilted and slightly folded within the Tertiary, but nonetheless have a present-day flat FWL, and this is because this structure has received very recent, top-up oil charge (Kester, 2011). But retaining a flat contact after tilting depends on oil density, wettability, reservoir permeability, capillarity etc).



Tilted Palaeo-Contact



Impact on field development



The extent of the field as defined in two different assumptions, flat contact at -1289 tvdss or tilted contact. The development plan of the field is impacted by these scenarios. The appraisal plan of the field should accommodate for further understanding of the hydrocarbon distribution in the field.