Hydrodynamism and Petroleum Trapping

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SUMMARY

Hydrodynamic flow exists in almost all geological basin types of the Wilson cycle, from passive margins to foreland basins to mountain chains. There are two hydrodynamic settings where flow is either centripetal and gravity driven, or centrifugal and compaction driven. In both cases, hydrodynamics can enhance hydrocarbon trapping. The magnitude of the tilt depends on the overpressure variations, the lateral permeability variations and the hydrocarbon fluid type which leads to differences in buoyancy pressure. Gravity driven processes are particularly important in the Arabian Shield (Qatar, Saudi Arabia) and North Africa (Algeria, Libya). Compaction driven-centrifugal and gravity driven-centripetal phenomena can co-exist in the same basin, e.g. Mahakam (Badak and Tunu, Indonesia) or Douala Basin (Cameroon). Turbidites (Nigeria, Mississipi Delta) correspond to centrifugal settings, with mainly lobes and faults. The role of faults as partial permeability barriers may be a significant regulator for flow in both centripetal and centrifugal settings (e.g. South Caspian Sea, deepwater Nigeria).

Introduction

Traps resulting from hydrodynamic flows have been evidenced in Petroleum Basins and been described in detail by several geoscientists in the past, emphasizing the fact that "fluids are moving rocks" mainly ruled by their pressure regimes, the sealing or carrier beds entry pressures and or hydraulic fracturation pressures.

Hydrodynamism is related to the massive or diffuse circulation of often fresh waters in sediments due to their pressure field variations.
Darcean water flows are well known and observed in sedimentary rocks that are wettable (entry pressure being less than buoyancy pressure) and permeable to a certain extent - except evaporites.

-Onshore, the meteoric water influx into carrier beds exposed in outcropping topographic surfaces (recharge area) induces an artesian (called centripetal or gravity induced) flow of waters from edges to the centre of the sedimentary basins. The phenomenon due to uplift (then often active in mountain chain areas) generates water head differences and can be also observed from salinity and temperature variations (fresh to salt water and cold to warmer respectively).
Discharge area can be induced by such erosional surfaces, faults...

-Offshore, the Artesian flow is usually not significant as recharge areas are very remote, and discharge areas problematic in deep parts of oceans.
The already observed pressure water head gradients from centre to edges of the sedimentary Basins imply that formation waters do flow in such offshore Basins as well.
In this case the disequilibrium of compaction mainly linked to fast sedimentation rates and subsequently undrained condition onsets, mainly drives pressure field variations.
Water flows are produced into more permeable carrier beds (this process is called centrifugal or compaction induced process).
The excess water is generated by the dewatering of undercompacted shales.

This hydrogeologic centrifugal behaviour was described by King M. Hubbert in his '60s papers, André Chiarelli in his PhD memoir in 1973, and much more recently by authors like Richard Swarbrick (2008) and Yves Grosjean (IPTC, Doha, Qatar 2009). In any of these hydrodynamic contexts, tilted hydrocarbon-water contacts (Figure 1) have been observed where the direction of the tilt is clearly indicative of centripetal or centrifugal flows of formation waters.

Examples

Many examples are related to shelf deposits having a sufficient extension but heterogeneities of permeability to allow the hydrodynamic phenomenon to exist and water flow flow to be developed as far as possible.

The North Dome gas field in the Khuff Fm and the Cretaceous Al Shaheen oil field of Qatar, the Ordovician Tin Fouye Tabankor oil field in Algeria, Villeperdue field in the Paris Basin are such centripetal examples, where aquifer pressure potential and salinity gradients are indicative of a hydrodynamic flow originating hundreds of km to the southwest, in the Arabian or African cratons or Basin edges.

The discharge area remains essentially speculative and could be related to piercing salt domes or to Hercynian unconformity with a contact between Ordovician and Trias sandstones.
Other famous examples are those present in Mahakam deltaic province, with the observation of the coexistence of a centripetal behaviour onshore (Badak oil field) and also a centrifugal one located offshore (Peciko, Tunu gas fields, Stupa gas field) (Grosjean, 2009).

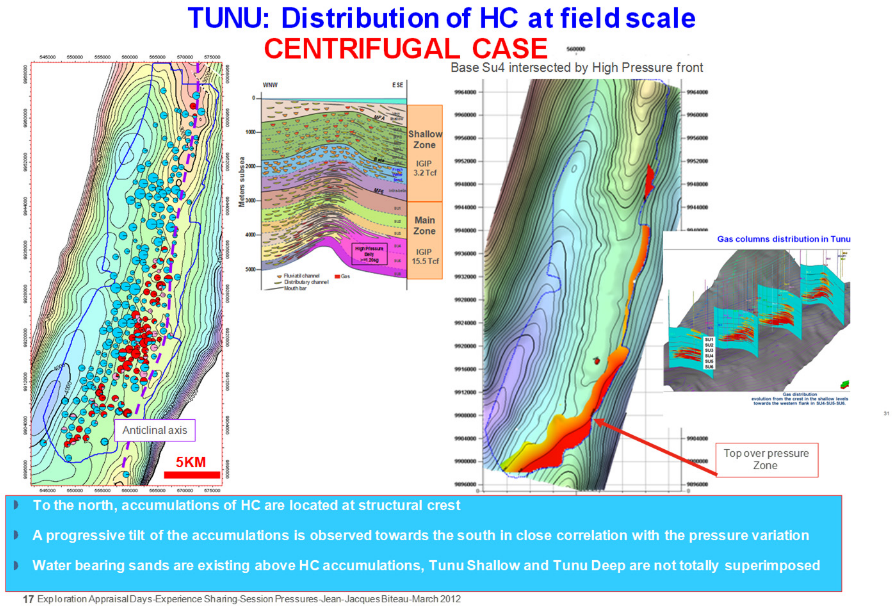

Figure 1 *Tunu Case Study Example.*

In the South Caspian Sea the examples of Shah Deniz, Azeri-Chirag-Guneshli and Absheron are representative of a major centrifugal hydrodynamic process in a very recent deltaic environment.

In 2011 Absheron was decided and located downdip from a former well that was drilled water bearing 10 years before: this was a very successful result at the end.

More recently hydrodynamism has been demonstrated in turbiditic environment (lobe and channel type depositional complexes, in huge deltas such as Gulf of Mexico, Niger Delta, Lower Congo Basin), but with more subtle existing tilts probably limited by the relative weakness of flows in more confined sedimentary systems.

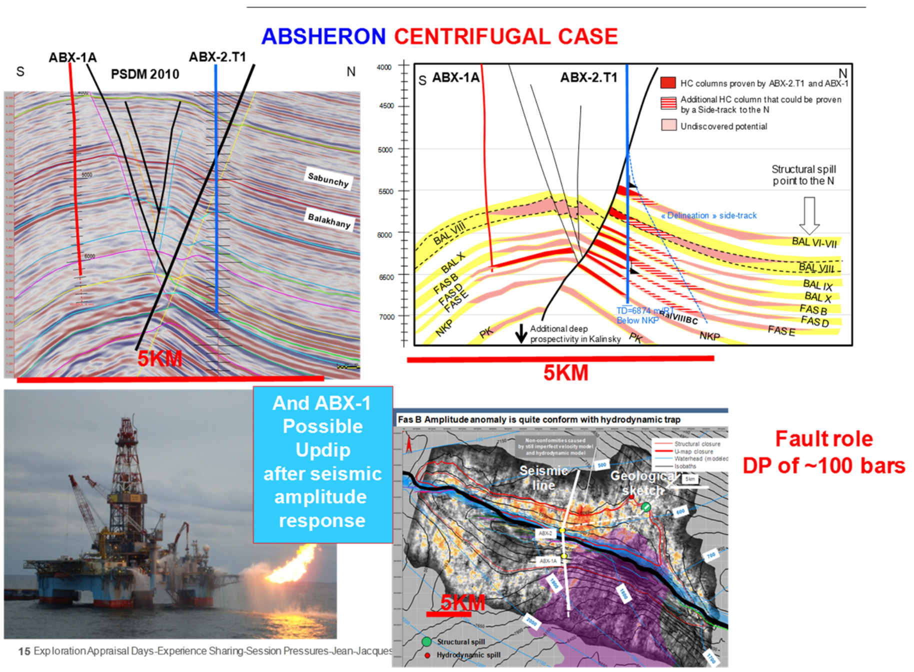

Figure 2 *Absheron Case Study Example.*

No doubt that the quest for similar enhanced trapping components will be a major issue for the petroleum exploration worldwide in the coming years especially in turbiditic depositional environments where this phenomenon has been ignored or discarded.

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