VERTICAL HYDROCARBON SEAL RETENTION IN DEEP OFFSHORE TERTIARY BASINS

Dominique Grauls, Jean Loup Montenat and Marc Lescanne
TotalFina Elf –64018 Pau France

In deep offshore Tertiary basins the hydrocarbons trapped in turbiditic plays are very often found at shallow burial in different structural settings. These traps are also characterized by important 4 way or 3 way-dip closures sometimes exceeding 1000 meters especially in ultra deep imbricate fan system. Assuming that the hydrocarbon charge is efficient enough to completely fill traps the key issue is to predict the maximum hydrocarbon column height (gas, oil or both) that can be trapped by top or fault seal or conversely to check if the initial hypothesis made for the column height is consistent or not with the sealing efficiency of your trap. This paper tries to deal with this problematics and to summarize the main conclusions obtained from « seals and traps » case studies in deep offshore. Focus is on conventional and fault-related traps in sand-shale clastic environments both in normally and overpressured settings.

Conventional traps (4 way-dip closure) *in normally pressured systems*

When a trap is not filled up to spill, the maximum hydrocarbon column height will be constrained by the following parameters: burial, seal facies (sand content) and/or degree of microfracturing, in-situ fluids density, aquifer pressure regime, minimum seal retention threshold (capillary or hydrofracture). Hydrofracturing and capillarity are considered the principal leak modes. Molecular gas diffusion through the water phase is also observed in deep offshore but this long term process at geological time scale does not really impact the preservation of hydrocarbons in context of recently active petroleum system.

In normally pressured domains of the deep offshore, shale-dominated seals are often encountered at shallow burial (depth less than 1000 meters for gas). Low minimum effective stress conditions are associated to this specific setting and favor hydrofracture leakage. In-situ stress data and capillary measurements through the 500-1500m burial show that the hydrofracture threshold in shale-dominated mudrocks (Vsh>80%) is reached before the capillary threshold.

Capillary leakage however is the predominant mechanism for shale-prone seals (for gas) at burial depths exceeding 1000m and at any burial for sandy shales and/or microfractured seals as both factors significantly lower the capillary entry value of seal.

The thickest hydrocarbon columns range from 600 to 1000meters at shallow burial (less than 1000m). This high sealing retention is due to the shale-prone (Vsh>70%) facies and the aquifer normal pressure regime. Two-phase hydrocarbon columns are more frequently observed. The presence of a gas cap enhances the trapping capacity to oil as the capillary entry pressure for gas exceeds the entry pressure for oil (P_e gas > P_e oil)

The shortest HC columns (less 200 meters) are very often associated with an increase of the vertical permeability of seal due to microfractures or/ and an increase of sand content in seals. Oil bearing structures are more frequently observed due to the gas capillary leak.

Conventional traps (4 way-dip closure) *in overpressured systems*

In sand shale sections compaction disequilibrium appears below 1500-2000m /sea bottom and is associated with a decrease of net to gross or drainage efficiency. Overpressuring develops through these undercompacted shaly seals that are acting as « *pressure seal »* for hydrocarbon bearing traps .The overpressure in shales is slightly higher than the overpressure in traps. The effect of this « pressure seal » prior drilling is difficult to assess but can be tentatively predicted from seismic velocities provided that seal thickness exceeds 50m. For these undercompacted seals a capillary leak mode is unlikely as the capillary entry value (added to the pressure in shale) is far in excess of the hydrofracture criterion.

Overpressures induced by compaction disequilibrium do not usually favor hydrocarbon preservation. That for 2 main reasons: first because the column height decreases with the reduction of minimum effective stress, second the overpressure built-up before the hydrocarbon charge prevents the trapping of significant hydrocarbon columns. The tallest hydrocarbon columns rarely exceed 200m in weakly overpressured domain. More than 70% of hydrocarbon accumulation is found in normally pressured traps overlying the undercompacted domain.

The hydrocarbon column height rapidly decreases as the reservoir pressure magnitude in the aquifer approaches the in-situ minimum stress or hydrofracture criterion. Hydrofracture leakage becomes rapidly predominant and well accounts for water-bearing traps.

Fault-related traps (3 way-dip closure) *in normally pressured systems*

In normal pressure regime conditions and clastic depositional systems the fault seal efficiency is controlled by capillary leakage. Parameters that control the vertical hydrocarbon retention include the fault « facies » or the composition of the fault gouge, the depth of burial and the magnitude of fault throw are the key parameters. High SGR (shale gouge ratio) values associated with low net to gross faulted intervals allow the fault facies to reach high capillary entry pressure values and then high sealing retention. This clay smear mechanism allows hydrocarbon column heights in excess of 500m (0.7 s.g .oil) at shallow burial (1000meters). In opposite low SGR values will be associated to thin hydrocarbon legs (less than 100m).

Fault-related traps (3 way-dip closure) *in overpressured systems*

In overpressured systems the pressure magnitude of aquifer becomes more critical than fault facies. Increasing aquifer pressure regime in traps tends to lower the fault seal retention especially for faults experimenting lower SGR value.

Overpressuring plays also a key role in ultra deep offshore and imbricate fan systems induced by compression. High pressure magnitude at decollement level is associated to a transiently active compression. Overpressures constitute the major driving force for fluids to migrate up to sea floor during the periods of stress relaxation. During these periods of dilatance faults behave as highly permeable conduits. The fault seal retention in this tectonically active domain is then very poor and and hydrocarbon accumulation can not exceed a lot the 4 way dip closure.

In summary hydrofracture and capillary leak modes are in competition for the control of the vertical hydrocarbon retention of cap rocks and faults in deep offshore. Pressure in shales influences the ability of the seal to hold a hydrocarbon column in place in overpressured systems. As the seal « facies » (sand content and degree of fracturing) is likely the first order parameter that affects the vertical seal retention in normally pressured systems the aquifer pressure magnitude becomes rapidly the predominant factor in overpressured systems. Vertical fault seal still remains a challenging area and additional research is needed to move towards a more quantitative prediction.