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Origin of Abnormal Pressures, Hydrodynamism and Pore Pressure Prediction

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SUMMARY

Current Frontier exploration is bringing us to drill into increasingly highly pressured sedimentary intervals as well as hydrodynamic flows. In these Frontier contexts, lack of well calibrations & poor understanding of the pressure generating mechanisms lead to ever increasing uncertainties in our pore pressure prognoses.

Total's experience of all mechanisms of abnormal pressures shows that our in-house shale pressure modeling is quite accurate and reliable with conformity rates between the prognoses and results close to 100%. By taking a step back, it has been noticed that the greatest uncertainty lies within the reservoir pressures and that these are 100% linked to the understanding (or lack of) of the 3D geological model. All recent cases where the pressure results are significantly different from the prognosis are always linked to errors on the geological model used to estimate the reservoir pressures.

Thankfully, Total's philosophy for pre-drill pore pressure prognoses, follow-up while drilling and post-mortem analysis has allowed us to reach 100% of exploration objectives while keeping the highest safety standards & not put our operations at risk in case of non-compliance to the PPP modeling. We are putting great efforts to maintain this track record and striving to refine our methodologies.

Introduction

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A few case studies will be discussed to illustrate operations in narrow drilling windows and the lessons learned.

Design of a well architecture

To design a well architecture and safely drill it, a complete Pore Pressure profile is needed in:

- Shales: Pressures can be modeled based on indirect indicators of porosity evolution. They cannot be measured due to a too low permeability.

- Reservoirs: Pressures can only be deduced & calculated based on hypotheses describing the geological model & connectivity / lack of connectivity with calibration points (wells in the vicinity).

- Source Rock: No proven indirect method today to estimate PP.

A disequilibrium of compaction often generated by a high subsidence rate may generate a drainage inefficiency and so generate a pressure anomaly and a porosity anomaly.

The classical method proposed by Eaton or ratio method differentiates

- normal compaction with weight of overlying sediments is supported only by the matrix and the Fluid pressure is hydrostatic,

- abnormal (Under) compaction where the weight of overlying sediments is supported both by the matrix & fluids and the Fluid pressure is no more hydrostatic. The shift of the sonic transit time is proportional to the abnormal porosity and consequently to the overpressure.

This method is used in combination with interval velocity analysis from seismics to determine what is called a PShale.

In fact the vertical stress is linked to the effective stress by the equation $S_v = P_{shale} + S_e$. $P_{shale} = P_{sh} = \sigma_v - [(\sigma_v - P_h) * (\Delta t_n / \Delta t_o)^m]$, the second term of the equation being the effective stress, with Δt interval transit time in microseconds per foot, P_h the hydrostatic pressure.

Several cases may occur with PShale being at the level of PReservoir, which generally means a very undrained system and high pressure shales.

The case with $P_{shale} > P_{res}$ is present when the system is partially open, this is a nice case study evidenced for example in the Caspian Sea with the 2012 discovery of Absheron where hydrodynamic behavior is prominent.

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Figure 1 Examples of drained and undrained systems.

The last case with $P_{\text{Reservoir}} > P_{\text{Shale}}$ may be encountered in cases of lateral transfers through faults or highly steeping dips of the reservoir section or when the reservoir reaches the seal hydrofracturing pressure (S_{min} or S_3). The pressure will decrease until $P_{\text{Res}} = S_{\text{min}}$ at top of the crest of the trap.

Figure 2 Case with $P_{\text{reservoir}} > P_{\text{Shale}}$.

Total in-house method is to define two scenarios: the commitment and most likely cases. A geological Most-Likely case is proposed. It is the scenarios the subsurface geologist and the driller 'believe' in. It is not necessarily the P50. A Commitment case is built, considering the unfavorable Pore pressure scenario. This is a 'Geoscientist' instead of 'Mathematical' approach. Drillers asked to design the well on the 'Most Likely'.

Contingencies/equipment are ready if the Commitment case is encountered.

This is not a standard approach of the uncertainties in the industry

- Mathematical approach,
- Generally assuming $P_{res} = P_{sh}$
- The Drillers design the well on either P50 or P90 (HSE)

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