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Drilling Challenges Related to Geopressure Compartmentalization

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Abstract

In the process of testing a prospect, a substantial investment goes to drilling the first wildcat. Drilling problems related to bore-hole geopressure can present impediments to reaching the proposed depth. Most of the drilling difficulties take place at or near the interface between the seals (shale) and the reservoir quality beds (sand).The frequent disparity between the predicted pore pressure in the shale and the actual pore pressure in the sand causes such drilling problems.

Pressure transgression and regression take place in the subsurface reliant on the sedimentary and structural spatial settings. Sizeable transgressions of the pressure envelope lead to hard kicks, mud cut, bore-hole collapse (instability), hole packing off, stuck pipes, and unset cement. Conversely, pressure regression causes loss of circulation, hole bridging, sticking pipes and excessive torque.

Introduction

Well drilling prognosis, including mud weight and casing seats, is substantially driven by the subsurface development of the pore-fracture profiles. Pore pressure envelopes that shift as depth increases dictate the mud weight (density) needed to cap the formation's pressure in the open hole. Moreover, the drilling tolerance window between pore and fracture pressures dictates the number of casing points needed to reach the objective depth.

Several case histories from the Gulf of Mexico demonstrate that sizeable transgressions of the pressure envelope lead to hard kicks, mud cut, bore-hole collapse (instability), hole packing off, stuck pipes, and unset cement. Conversely, pressure regression causes loss of circulation, hole bridging, sticking pipes and excessive torque.

On site drilling surprises can be minimized in advance by forecasting depth to top of geopressure (TOG), pressure gradient changes in shale beds with depth, pressure envelopes shift (transgression-regression) in sand beds, fracture matrix coefficient, and expected hydrocarbon density and height. Therefore, pore pressure prediction using pre-stacked velocities (Eaton, 1975), in junction with geopressure basin modeling from the offset wells are vital for pre-spud well planning. It is essential to use all the geological building blocks to estimate the pressure differential between the seals and reservoirs expressed in PSI and PPG MWE (Shaker, 2003).

The failure to reach the exploration objective in some of these problematic wells was due to the faulty assessment of geopressure compartmentalization.

Concept and Methods:

The subsurface formation pore pressure (PP) profile is usually divided into two main segments: the upper, normally pressured (unconfined and hydrodynamically active) and the abnormally geopressured (confined) section below (Figure 1). The interface between the two systems is usually associated with an increase in the pore pressure gradient (PG). Consequently, the depth to the top of geopressure (TOG) represents the pivot point at which to set casing and increase the mud weight to a density that can manage the pressure shift from hydrostatic to geopressured.

The geopressured system (below TOG) is usually confined and sealed from the free flow of the upper hydrostatically pressured section. The development of the geopressured compartmentalization setting is mainly driven by lithology, structure, principle and minimum stresses, and reservoir fluids type. Pressure gradient increases exponentially in the seals and follows the linear regional hydrostatic gradient in the reservoirs. Subject to fluid or gas density, the presence of hydrocarbon in the reservoir reduces the slope on this linear gradient.

Deposit of additional sediments in a structurally relaxed (extensional) basin leads to an increase of the principal stress and consequently results in a higher transgressive PP profile. This transgressive pressure (PT) profile is usually represented by a cascade shaped profile, as long as the basin subsidence accommodates the volume of sediment input with the absence of structural failure. Conversely, in the case of structural failure and/or when PP reaches the limit of the fracture pressure (FP), pressure regression (PR) takes place (Shaker, 2004). The common regression phenomenon is usually a result of the presence of communication paths through faults and salt interfaces between the deep, highly pressured reservoir and the shallower, lesser pressured reservoir. This leads to a substantial discrepancy between the predicted PP in the shale beds and the actual PP in the encased sand .

Fracture pressure (FP) represents the high perimeter where impermeable beds yield to hydraulic fracturing by reaching the matrix minimum stress. The difference between the FP and PP usually represents the "Drilling Tolerance Window". The drilling mud pressure ideally stays within the limit of this window. The tolerance window (FP-PP) varies in magnitude depending on the PP envelopes shift and the associated FP values. It tends to be narrow (less tolerant) in the normally pressured, shallow young deposits and the deeper, high pressure / temperature environment (HP/HT). As a result, shallow water flow (SWF), hydraulic fracturing, loss of circulation, and flow-kill-breakdown cycles are dominant drilling problems in this narrow window. On the other hand, a wider window (more tolerant) prevails in a large portion of the geopressured (< 0.8 PG) section. This leads to relatively fewer drilling problems. Hydrocarbon accumulation favors this wider window zone.

The size and direction of the pressure envelope's shift across the interface, from the seal (shale) to the reservoir (sand), are responsible for shaping the PP and FP profile with depth (Fig.1). In case of a large progressive shift, the bore hole can suffer a hard kick, especially if a hydrocarbon-bearing reservoir is encountered. Moreover, blow outs usually take place during a trip associated with swabbing and severe mud cut. Sloughing shale is a good indication of a PT, and this results in bore hole size enlargement in the shale beds above the high pressure reservoir. A faster rate of penetration (ROP) and high volume of connection and background gases is a good indication that the drilling bit is approaching a PT. Mud weight management at this interface is highly recommended. If substantial overbalanced mud weight is used to hold the well bore walls intact (stable) in the seals, a possible thick mud cake build up forms, facing the reservoir sandy beds below. Consequently, a larger hole forms facing the seals and a tight smaller hole forms facing the reservoirs.

In case of pressure regression due to structural failure (mainly fault cuts) and hydraulic fracturing, PP in the reservoir drops to a lower PP envelope. This leads to drilling problems, such as loss of circulation, hole bridging, sticking pipes and excessive torque.

Case Histories:

Two examples from the shelf and deep water of the Gulf of Mexico are shown here to exhibit the drilling problems and bore hole damages due to geopressure compartmentalization.

West Cameron Block 96, Well #1:

This well (OCS-G-15055 #1) was completed as dry and abandoned (D&A) by Kerr McGee in April 1998. A substantial increase in MW from 10.8# (5897 psi) to 16# (9226 psi) was applied to cap the PP increase in the process of penetrating the transition zone (Figure 2) between the normally and abnormally geopressured systems, (TOG). Subsequently, the pore pressure shows a transgression envelope at 11,200 feet and MW was increased to16.7# (11900 psi). Using both velocity and resistivity to predict PP, a geopressure regression at 12,500 feet was noticed. At that depth, pressure breach was most likely a result of the presence of a fault cut at this level. Due to the relatively overbalanced mud weight, and the proximity between the mud and fracture pressures especially deeper than 14,000 feet, several drilling obstacles occurred

Bore hole size was relatively gauged facing the shale beds and conversely, it was very tight in several sections facing the sand beds (Fig.2). This led to several hole bridges with high torque on the drill pipes and high tension spots on the wire line tools. The well was P&A.

East Breaks 689 #1:

This well (OCS-9192 #1) was P&A by Mobil in August 1994. The pore pressure transition from the normal to the geopressured system (TOG) was gradual (Figure 3). MW was increased from 9.5# (4199 psi) to 10.0 # (4836 psi), penetrating the transition zone (between 9300 and 10,500 feet). A hole enlargement (± 6 inches) took place in the shale cap above the TOG. Subsequently, a subtle pressure transgression took place at 11,200 feet and the MW was raised to 10.7# (6232 psi). Due to the close proximity of the PP and the MW, bore hole instability resulted in a washout section of the bore hole shale beds between 11,300 and 11,700 feet.

Balancing MW in relation to PP and FP:

The above two examples show the importance of monitoring the MW and adjusting it in relation to the drilling tolerance window (FP-PP). This is pertinent especially across the seal/reservoir interfaces where PP shows transgression/regression. MW at the rig floor is usually less dense than the mud at the bottom hole due to pump pressure, drill pipes and cutting. The ECD (equivalent circulating density) or mud hydrostatic measurement attained while drilling should be used for calculating mud pressure.

Managing the mud weight (including viscosity, and additives) in relation to the predicted / calibrated geopressure profile is vital to reach the objective depth. MWD, LWD, Mud logging measurements including MW, ROP, gas, temperature, mud pit level..etc. are very helpful to foresee PP profile changes ahead of the drilling bit. It is important to keep the MW in balance (+/- ½ ppg higher) with the PP and below the FG (dictated by the leak off test) i.e. within the tolerance window.

Pore pressure prediction using the pre-stack seismic velocity helps to approximate the PP profile. Calibration of the seismically predicted PP is a prerequisite to foresee the expected drilling trouble spots and estimate the drilling tolerance window in a proposed location. Therefore, integrating the pore pressure modeling using the geological building blocks and the available pressure - fracture data from the offset wells is necessary for the final calibration.

Conclusions

Geopressure compartmentalization is a double edged sword. It is the main catalyst for hydrocarbon entrapments, and yet it causes PP shift which creates drilling problems. Most of the troubles spots commence at the interface zones between the seals and reservoir type rocks. Pressure transgression and regression take place at the interface zone due to the geological setting and state of stresses in the basin.

In the transgressive zone, a larger hole can be developed in the seal and a smaller one facing the reservoir. This leads to bore hole collapse (instability), packing off, stuck pipes, unset cement, and ambiguous logging measurements. The released formation fluids and gases can cause severe mud cuts, unset cementing job, hard kicks, and possible blow outs. Penetrating the reservoir with overbalanced mud results in loss of mud and a relatively thick mud cake. This leads to sticking pipes, hole bridging, high torque and erroneous logging measurements.

Drilling the regressive zones, with overbalanced mud, usually creates a hole bridging (tight), sticking pipes and excessive torques facing reservoirs. In addition, petrophysical logging and formation pressure tools measurements can be distorted due to the presence of relatively thick mud cake.

Pre-drilling, pore - fracture pressure prediction is essential to dependable wildcat drilling prognoses. During drilling, it is important to administer the MW program, especially the ECD, to keep the bore-hole stable in the shale zones and free of bridges facing the sand zones.

Nomenclature

LWD = logging while drilling
MW = mud weight
MWD = measuring while drilling
PPG MWE= pound per gallon mud weight equivalent
PSI = pound per square inch
PR = pressure regression
PT = pressure transgression

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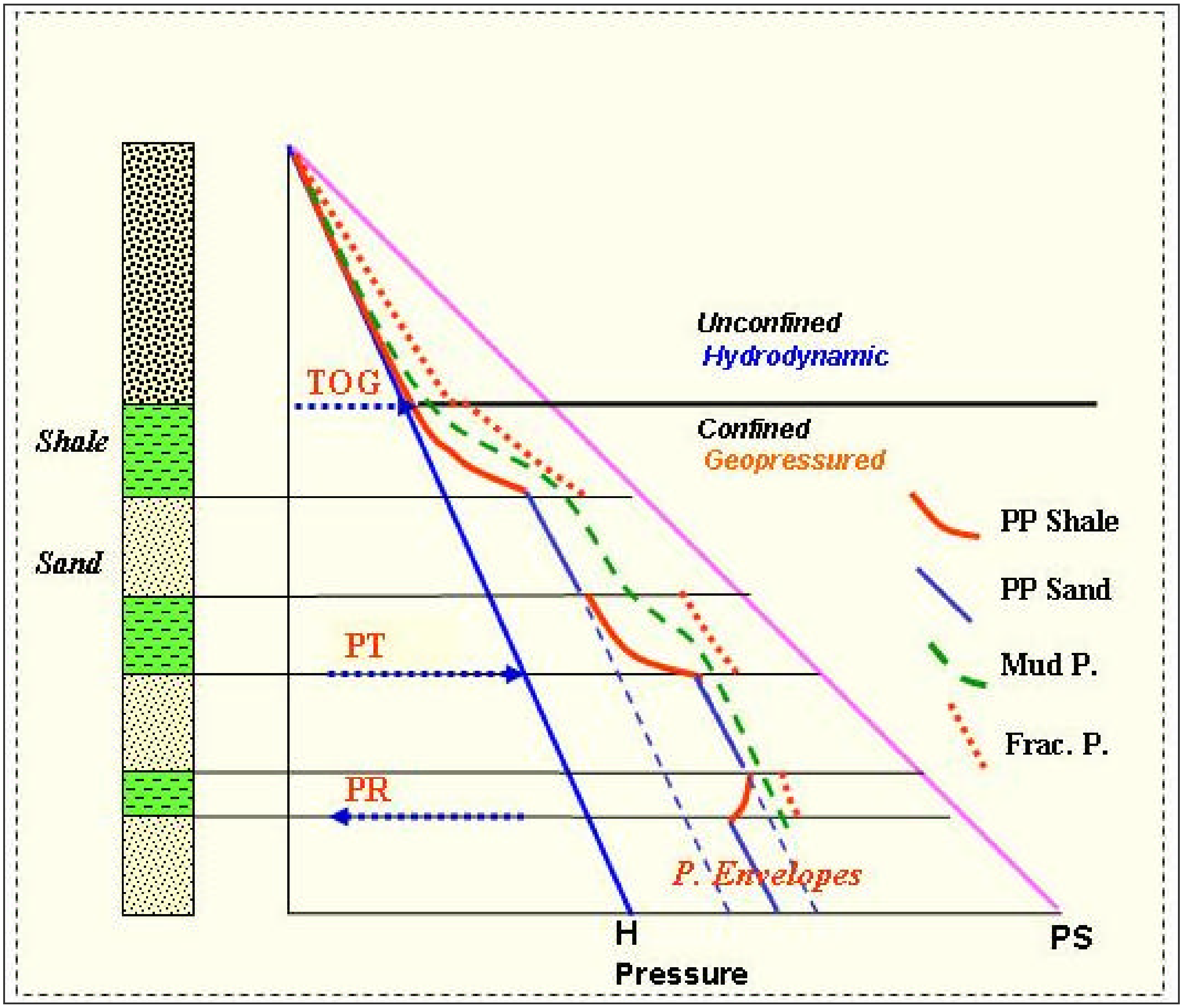

Figure 1- A generic pore pressure plot shows the different compartments- top of geopressure (TOG), pressure transgression (PT), pressure regression and pressure envelopes. Hydrostatic and principal stresses are represented by H and PS respectively.

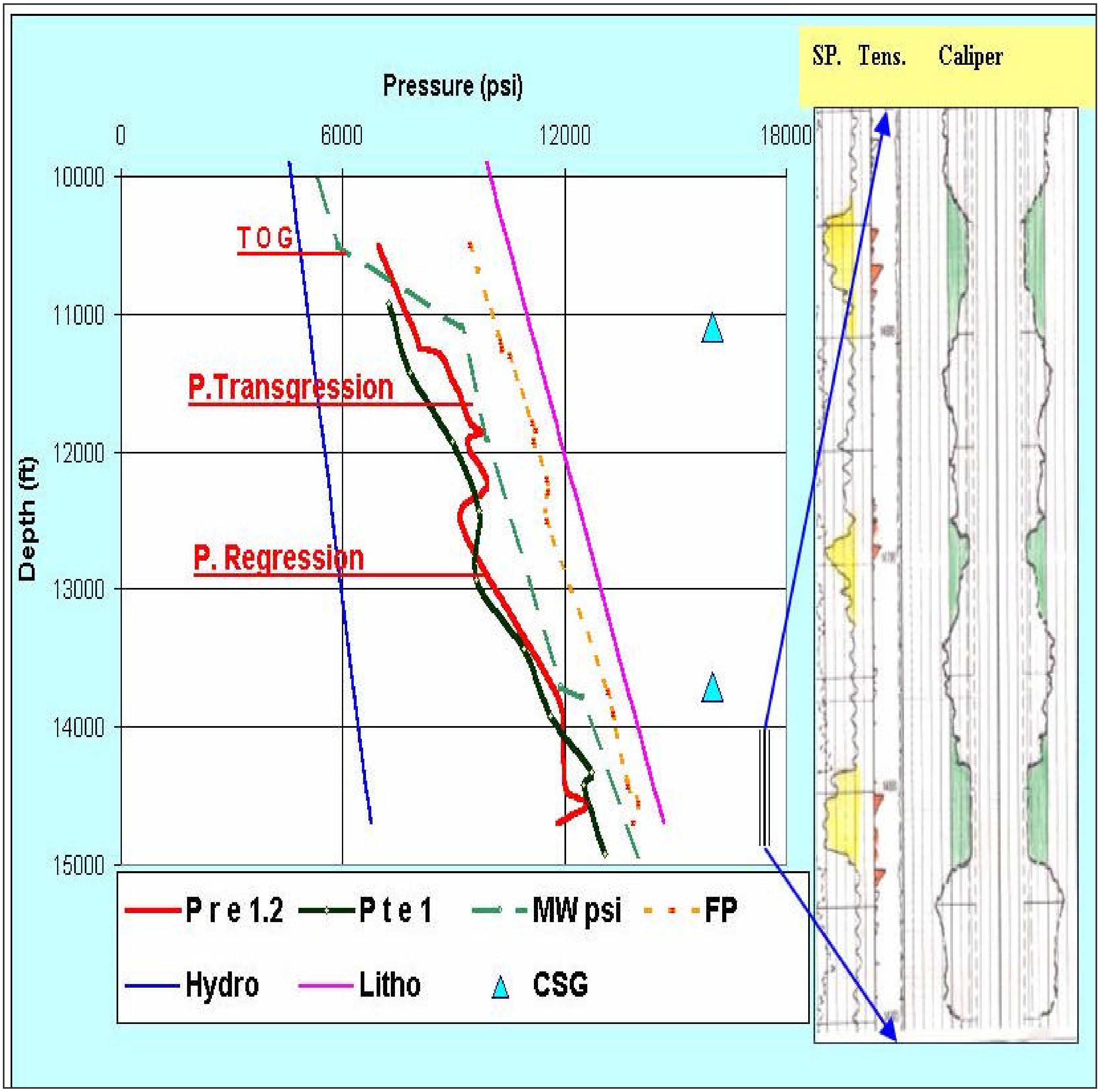

Figure 2: On the left, a pore pressure plot for West Cameron 96#1. Pr and Pt represent the predicted PP using resistivity and velocity respectively. Fracture pressure (FP) is calculated using resistivity. On the right l, an open hole profile shows bridges (green) facing sand beds and gauged hole opposite the shale beds. Notice the high tension (red) across the bridges.

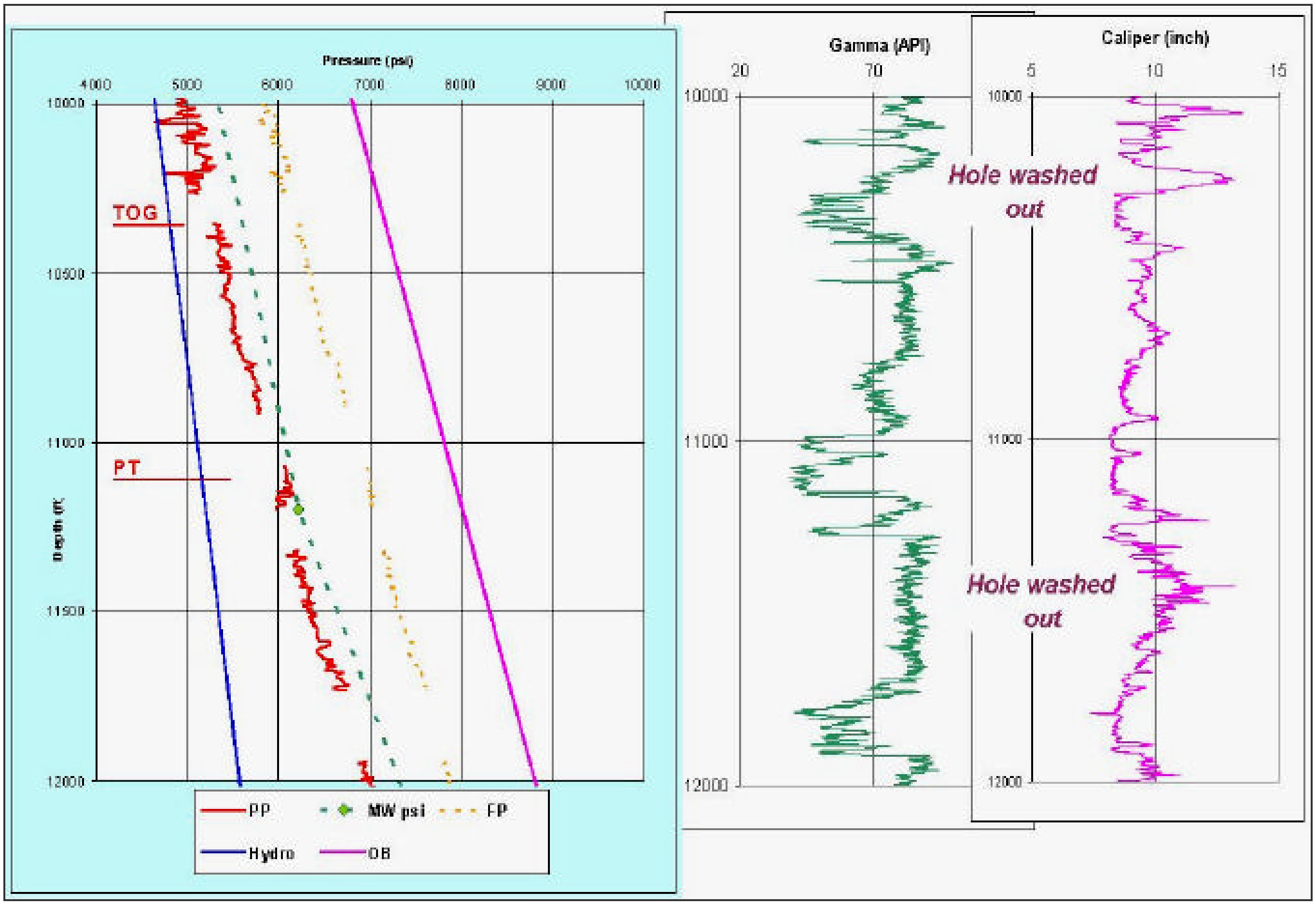

Figure 3 : On the left, a predicted PP - FP profile using sonic for East Breaks 689#1. On the right, a GR - Caliper plot for the open hole shows the large wash outs of the shale section above the TOG and within PT section.