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Pore Pressure Predictions in the Challenging Supra / Sub-Salt Exploration Plays in Deep Water, Gulf of Mexico.

Introduction:

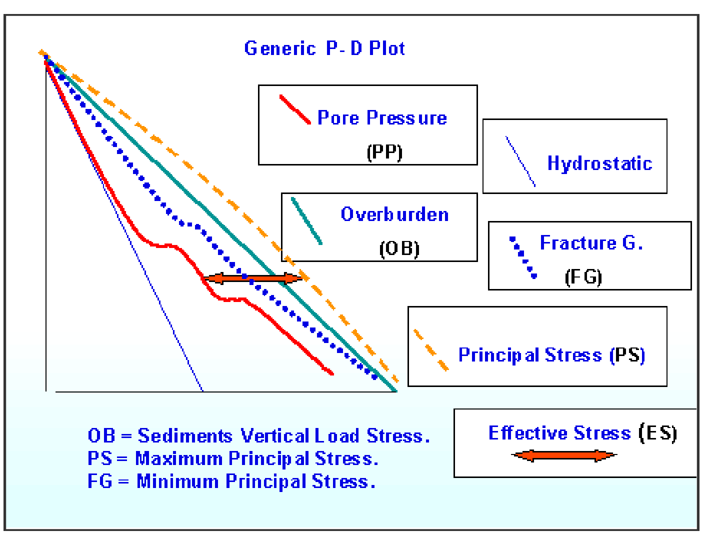
Geopressure profile in the GOM Tertiary-Quaternary sediments is mainly caused by compaction disequilibrium phenomenon. Lithology and Maximum Principal Stress essentially control this process. The unique salt petrophysical properties contribute to substantial changes in the pore pressure gradients in the host sediments above and below. Salt's low density is responsible for retarding the overburden gradient and its negligible permeability creates a perfect seal. Moreover, salt's ductile nature generates a variety of structure styles that impacts the stresses orientation.

In several sub-salt wells in Mississippi / Green Canyons and Garden Banks areas (MC 211,292, 619,627,674,714 / GC 153,699 and GB 217) a distinctive shift of the pore pressure and normal compaction trends takes place across the salt body. Lower gradient has been noticed below the salt and higher gradient above the salt barrier. On a salt-rooted mini-basin scale, a higher gradient was noticed in areas where the salt was emplaced and a lower gradient where the salt withdrew. The geopressure distribution in Auger Basin at GB 471and GB 602 exhibits this relationship.

Knowing the depositional model in relation to salt tectonics is very helpful in establishing the prospect's pore pressure profile and assessing hydrocarbon entrapment risk.

Definitions:

Stress fields, in particular the Maximum (PS) and Minimum (FG) Principal stresses determine the pressure envelopes in the subsurface sedimentary column. PS dictates the progress of the pore pressure (PP) and FG represents the breaching limit (Figure 1). Rock mechanics fundamental assumption is PP = PS – ES .



In salt basins the stress vector magnitude and direction are controlled by salt tectonics. Therefore, PS is not necessarily represents by the vertical load of sediments (OB). Salt buoyancy (SB) usually acts upward and has the tendency to accelerate and decelerate the PS above and below the salt respectively.

Figure 1: Definitions on Generic P-D (Pressure – Depth) Plot.

A brief discussion associated with different geological models and case history examples follows:

Salt Ridges, Domes and Structural Highs Associated with Salt Emplacements:

The buoyancy of the salt body (SB) acts upwards due to the density difference. This leads to an additional acting loading stress, beside the OB, on the sediment column. In this case PP = PS (OB + SB) – ES (Effective Stress) above salt ridges and domes which is greater than the assumed OB – ES in the case of mature and stable base basin (Figure 2). Therefore, acceleration of PP and FG above the top of these salt emplacements reflects the underlying salt upward movements. It is noticed in several deep water wells that Leak Off Tests (LOT) exceed the overburden (OB) at some of the casing points. This is another indication of the presence of Maximum Principal Stress greater than the OB.

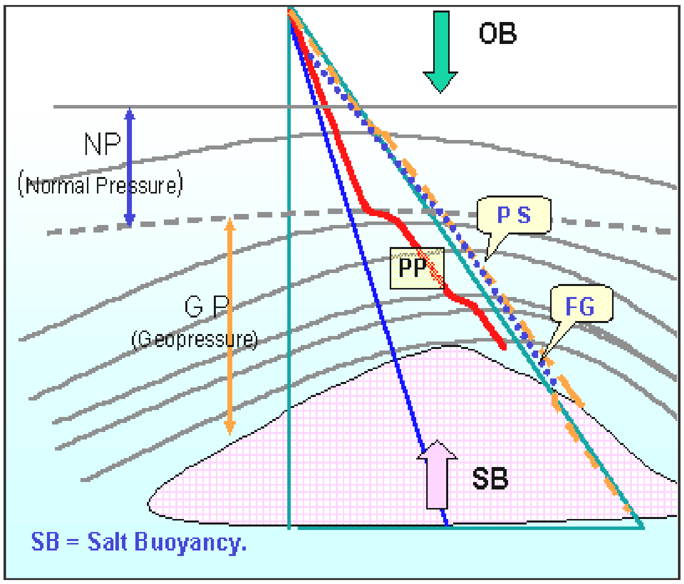


Figure 2: PP development on a salt ridge. The PP increases in a high gradient across the transition zone from the Normal Pressure (NP) to the abnormal Geopressure (GP).

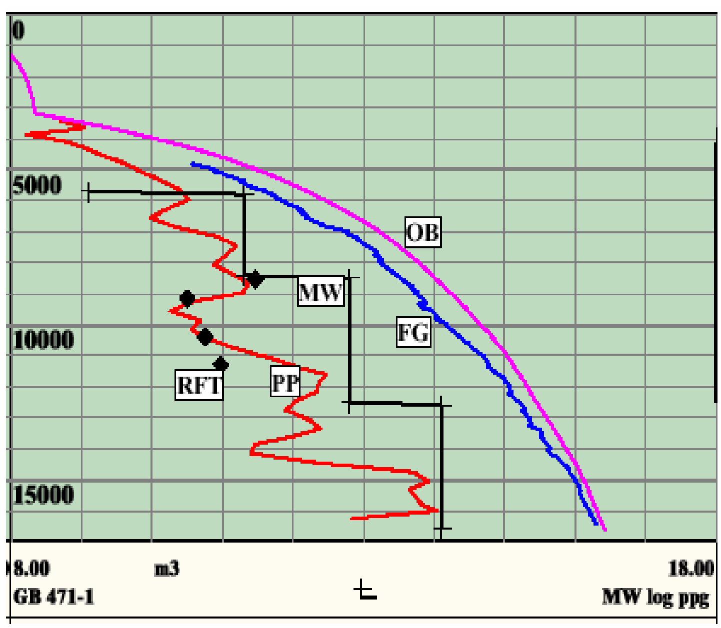


Figure 3: P-D in mud weight equivalent in Garden Banks well #1 Block 471 shows the Progressive increase of PP with depth. Notice the mud weight increased from 9 to 14 ppg in 10000'. RFT's represent the measured pore pressures. PP represents the calculated pore pressure in the shale beds.

Synclinal Salt Basins

In areas where the salt withdraws due to the rapid sedimentations influx, salt rooted basins form. Sediments thickness in some of these basins exceeds 25000'. Emplacement of the salt takes place upward away from the depositional passages. The contemporaneous salt movement from underneath the sediments column leads to creating unstable base giving way to the rock load. As a consequence, the PS can be less than the OB at basins low positions and compaction tends to retard. The development of pressure compartmentalization with highly effective seals does not dominate such exploration concepts.

The southern limb of the Auger Basin two deep wildcats in Blocks 600 and 602 (Macaroni) were drilled to depths exceeding 22000'and the mud weight (MW) used does not exceed +/- 13 ppg. Green Canyon well #1 in Block 908 (Fig.5) shows even slower PP development. The superimposed P-D plot on the geological model (Figure 4) sheds light on the interrelationship between the salt tectonics and the PP/FG behavior in the subsurface.

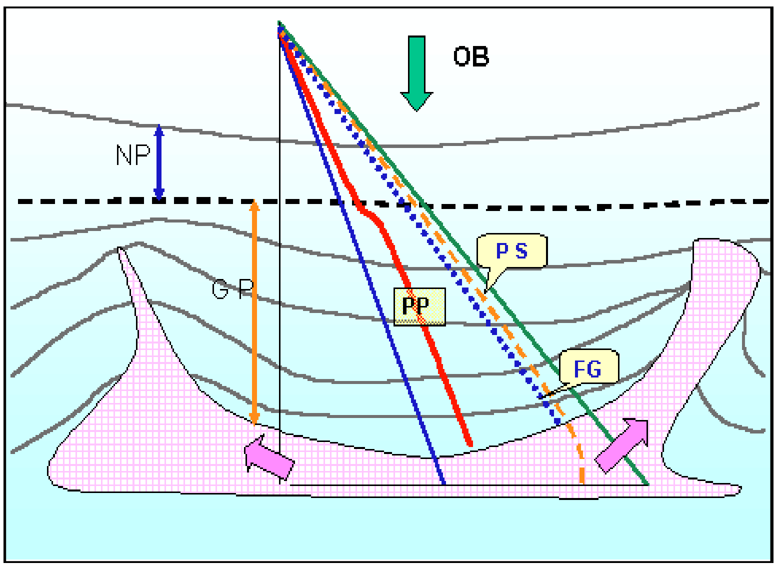


Figure 4: P-D plot in a salt withdraw synclinal basin.

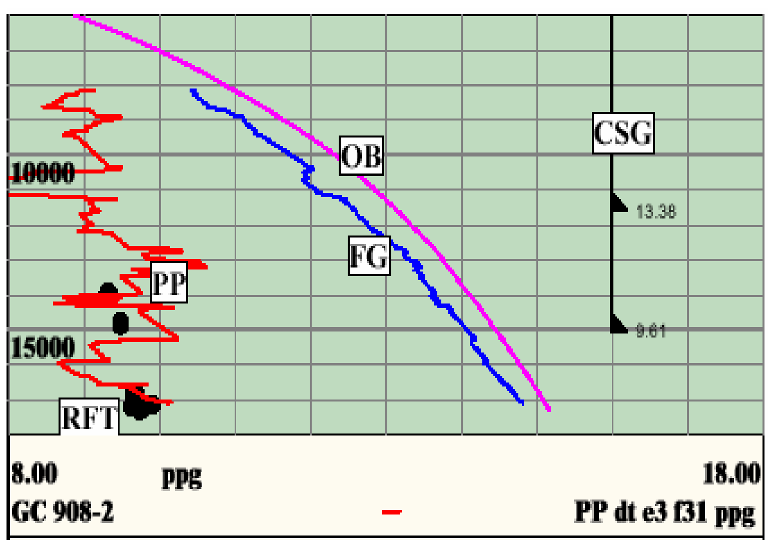


Figure 5: PP profile in MW ppge shows the slowness of the PP development in Green Canyon 908 #1. The pore pressure at the TD of the well was +/- 9.5 ppge.

Salt Flanks and Ramps

This exploration play is extensively targeted due to the advantage of combining the structural and stratigraphic elements to the trap. Due to the dipping nature of the on-lapping sediments (Figure 6) the PS is represented by the OB (vertical stress due to sediment load) in addition to the SS (shear stress due to sediment slip) and SB (salt buoyancy).

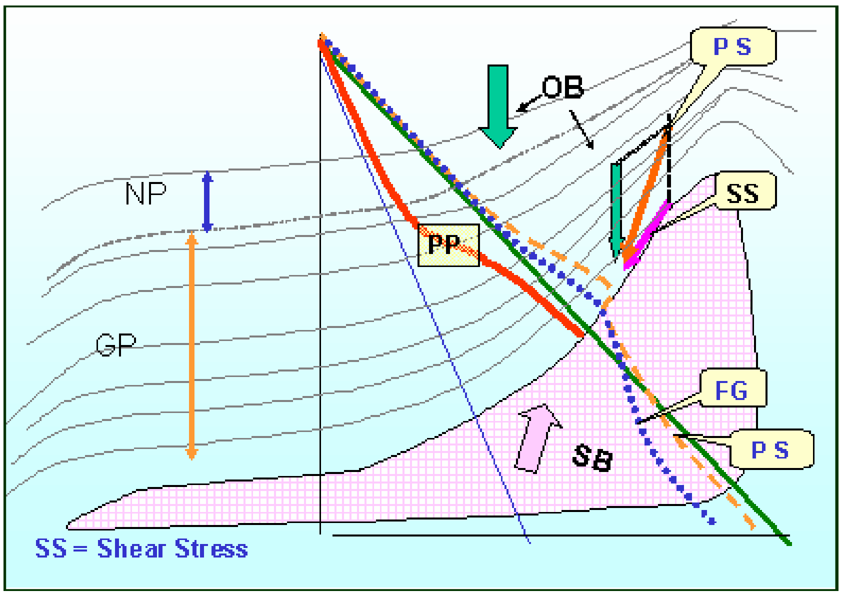


Figure 6: P-D plot superimposed on a salt ramp. Noticed the PS exceeds the OB due to the addition of the SS vector. FG sometimes exceeds the OB especially closer to the salt sediments interface.

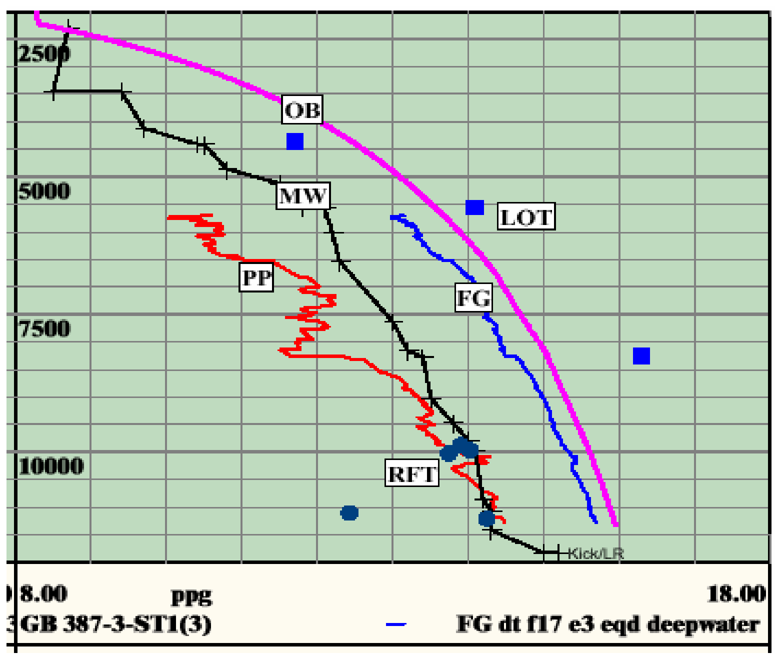


Figure 7: Calculated PP profile shows rapid increase with depth in GB 387#3. The LOT (leak off test) exceeds the OB in the deep part of the section. This confirms that the Minimum Principal Stress (FG) is relatively higher than the calculated OB. This leads to the assumption that the Maximum Principle Stress (PS) is much greater than the calculated OB.

Salt overhangs, Canopies and Sheets

The dynamic and emplacement history of these allochthonous salt bodies might be a complex issue to handle in this abstract. Therefore, density difference between the salt and host sediments will be considered the main driving mechanism for PP development. The salt body acts as floating seal. The sediment above is subjected to a PS sums the OB stress in addition to the salt buoyancy (SB). On the other hand, the PS on the rock column below the salt is reduced due to SB effect (Figure 8). The PP / FG gradients exhibit substantial changes across the salt body.

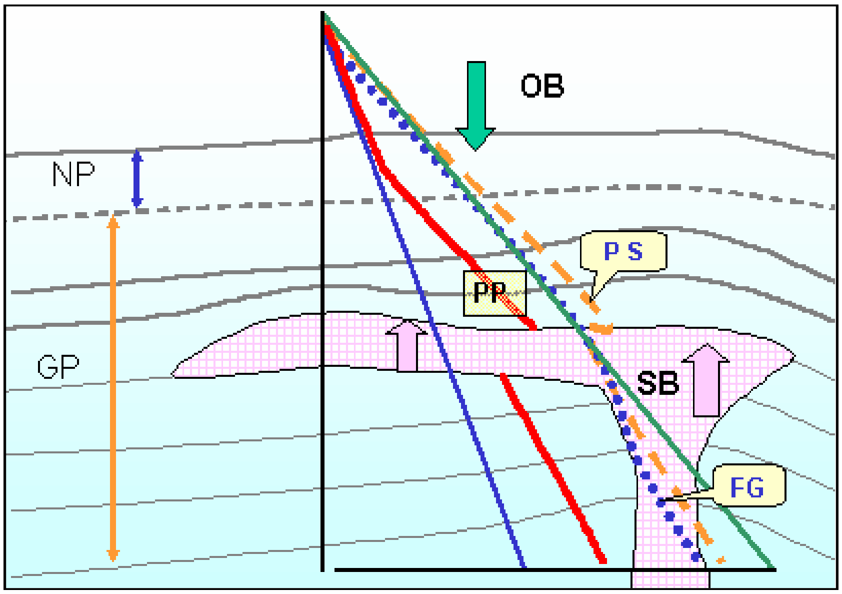
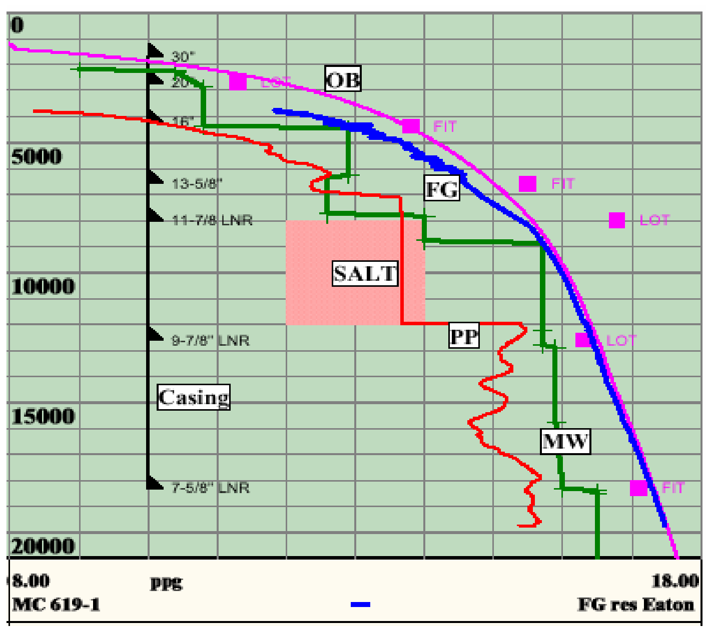


Figure 8: P-D plot for an overhang or canopy. Notice the downshift in PP below the salt. The PP increases in a faster pace above the salt and vice versa underneath.

Drilling is a challenging mission in sub-salt exploration targets. The faster development of the PP above salt requires higher mud weight and extra casing points (Figure 9).

Figure 9: P-D plot of MC 619 #1 well shows the PP/MW and FG above and below the salt. Notice the MW shows steep gradient above salt and low slope gradient below the salt. The measured FG (LOT/FT) is substantially higher than the calculated one. Five casing points were set above the salt to compensate for the rapid increase of PP. On the other hand, only two casing points were set below the salt to reach the TD of the well.



Rafted Blocks and Gouges

At the forelands belt of creeping massive salt sheet, similar to the Mississippi Fan Fold Belt in the Gulf of Mexico, rafted sediment blocks and gouges take place. If these older rafted blocks get cased with impermeable layers, PP will show a high gradient. In the case of gouged older sediment underneath the salt the shear stress will substantially increase and sometimes reduce the PP in this thin package underneath the moving salt (Figure 10). Sub salt gouges represent a drilling hurdle and hazard in frontier exploration plays. The SB will accelerate and decelerate PP above and below the salt respectively.

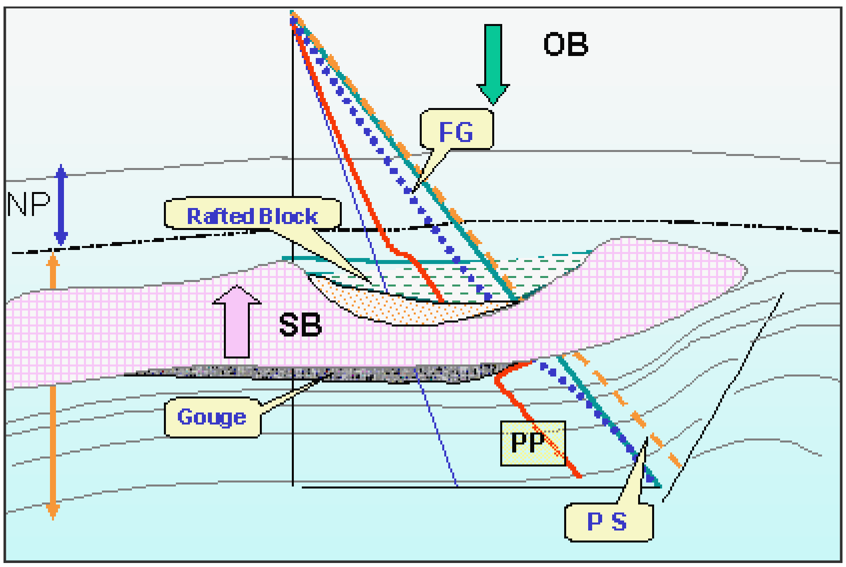
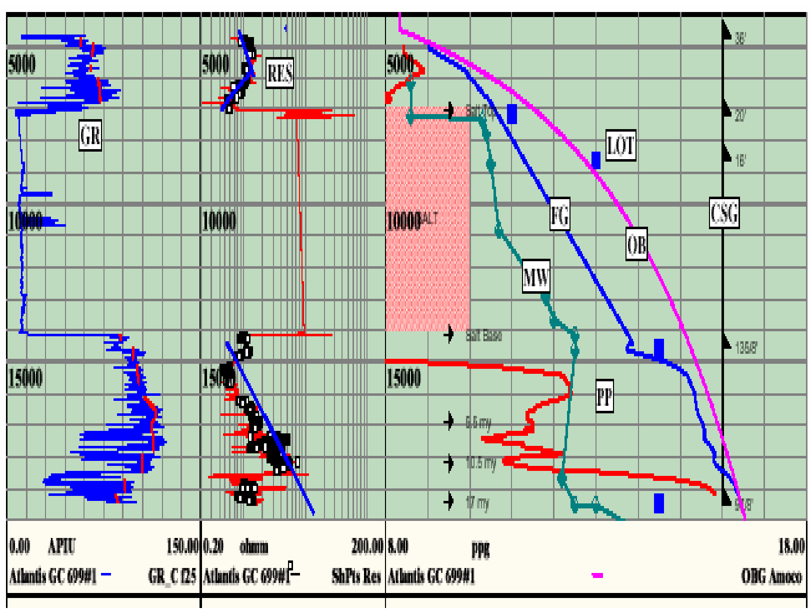


Figure 10: Geological model sheds the light on the geopressure profile above and below a down dip protruding salt sheet.

Figure 11: Pressure analysis display in Atlantis (GC 699). GR in the left panel, resistivity in middle and PP analysis to the right. At this location the rafted sediments is not thick enough to impact the rapid development of PP. Below the salt the PP show a regression and the LOT's followed that regression due the reduction of the PS due to the SB.



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