The controversial pore pressure conversion factor: PSI to PPG MWE

S. Shaker, Geopressure Analysis Services, Houston, Texas, U.S.

Geoscientists are inclined to use pore pressure (PP) plots expressed in PSI versus depth (P-D) because it is beneficial for prospect and play-concept compartmentalization and seal integrity appraisals. On the other hand, drillers and engineers use mud weight equivalents (MWE) in pounds per gallon versus depth (PPG-D) to prepare their well prognosis and carry out their drilling program.

The conversion method for calculating PPG from the actual measurements in PSI is usually computationally distorted, especially in a geopressured system. PP in permeable beds shows a positive gradient slope on the P-D plot but it generally has a negative slope on the PPG-D plot. This has been attributed incorrectly to several geopressure phenomena, such as regression, centroid, etc.

This article demonstrates how a new geologically based geopressure conversion modeling (GMC) compensates for erroneous values derived from using a universal (0.052) standard conversion factor (SCF). Moreover, this model simulates realistic geopressure compartmentalization and seal effectiveness in concordance with the actual measured values on the P-D plots and the drilling records.

SCF is derived as follows:

From lb/gal to psi/ft . . . $12 in^3/231\ in^3 = 0.052$
and vice versa
from psi/ft to lb/gal . . . $1/0.052 = 19.2$

The mathematically driven SCF, which is embedded in most pore pressure prediction software, converts from psi/ft to PPG MWE in all calculations without integrating lithology, compartmentalization, pressure differential between seals and reservoirs, structural setting, and hydrocarbon presence.

Conversely, GMC, which has been applied successfully in several wells on the shelf and deepwater, produces a comprehensive representation of the equivalent mud weight (EMW) needed to exert pore pressure in wet and pay sands. Moreover, it emphasizes the status of the subsurface compartmentalization as would be derived from a D-P plot and the drilling resume.

This article will use two cases to clarify the GMC concept—one in wet sand and one in pay sand.

Wet sands. Deep well 1 (TD 21 550 ft) in Keathley Canyon, offshore Louisiana, drilled by BP in Block 255 will show the difference between the SCF and the GMC conversion methods in wet reservoir sands. This well was selected because frequent repeated formation tester (RFT) measurements were taken in most permeable beds and the compartmentalization is clearly identifiable. Resistivity was used for pore pressure prediction in the shale beds (Eaton, 1975).

P-D plot expressed in PSI versus depth. In this case the top of the geopressured zone is identified at 11 600 ft (Figure 1). The PP profile is represented by cascade fashion pore pressure envelopes (PP RFT). Pressure transgression and regression are impacted by the sealing capacity of the shale caps and/or structural failure (Shaker, 2002). Slopes on the formation RFTs and mud weights show a positive slope (increasing with depth).

The plot shows three distinctive compartments: 14 000-16 000 ft (upper), 17 000- 18 500 ft (middle), and below 20 000 ft

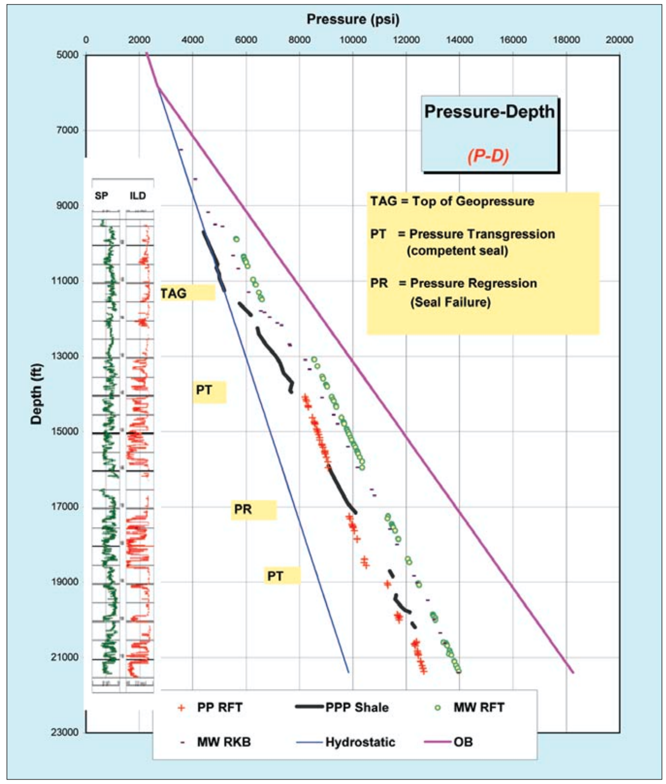

Figure 1. P-D plot of KC 255#1 expressed in psi versus depth.

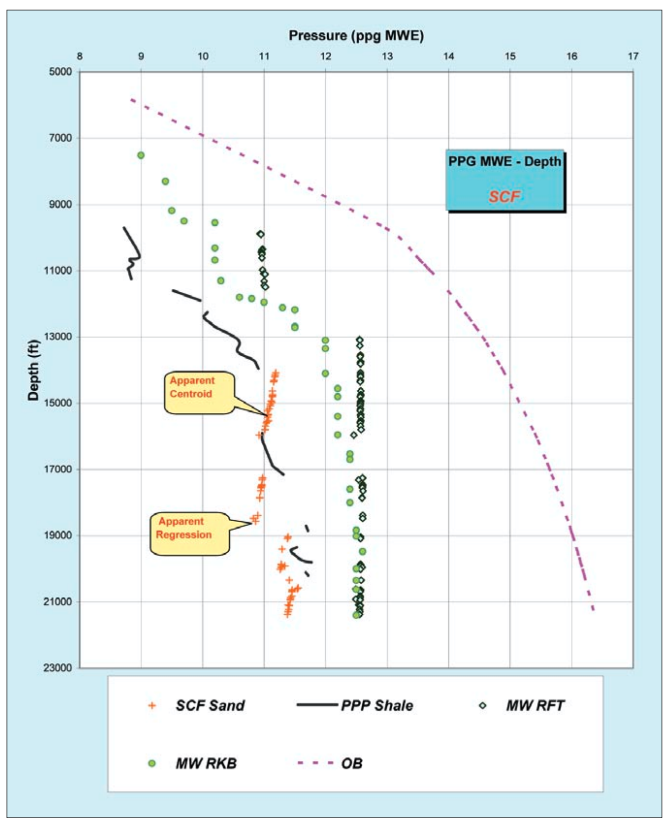

Figure 2. Pressure plot (KC 255 #1) expressed in ppg MWE versus depth using the standard conversion factor (SCF).

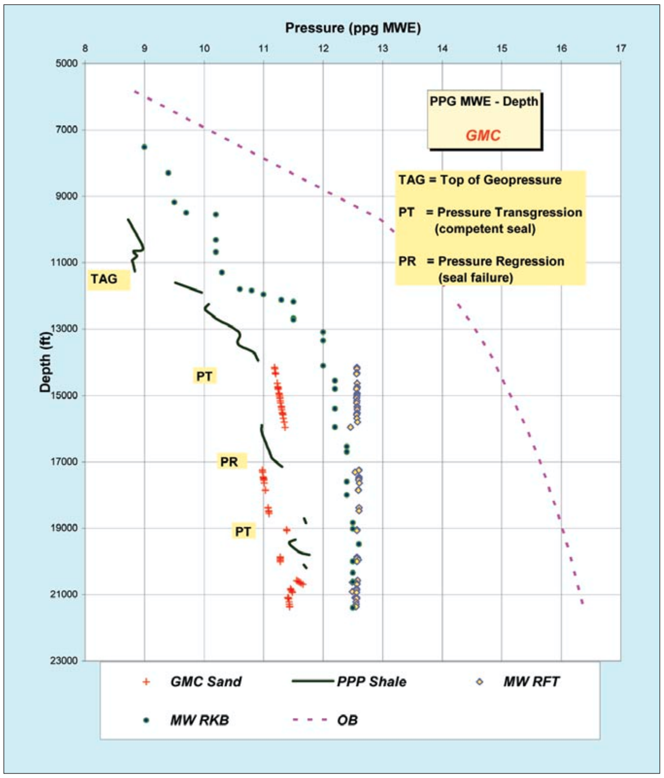

Figure 3. *Pressure plot (KC 255 #1) in ppg MWE versus depth using the geologic based geopressure conversion model (GMC).*

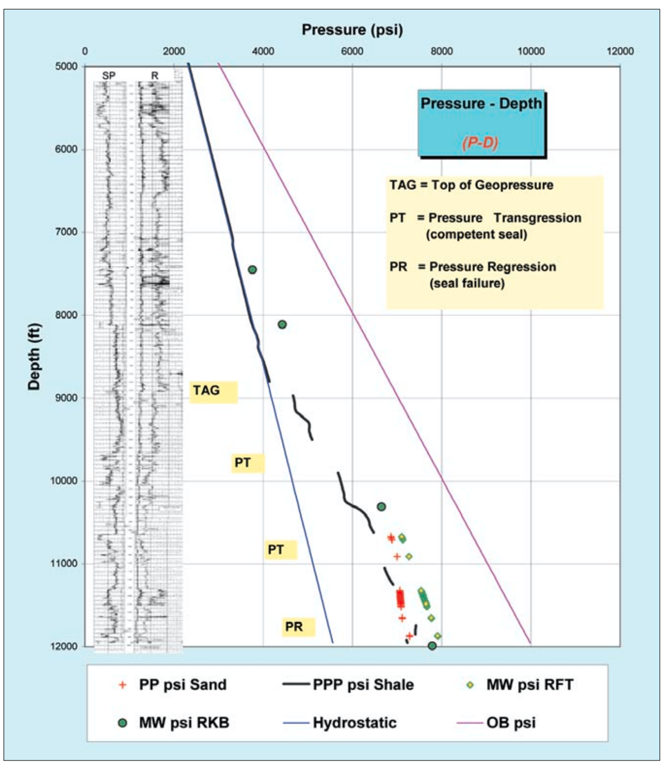

Figure 4. *P-D plot (EB 602 #1) expressed in psi versus depth.*

(lower). The upper and middle compartments are in communication. A pressure transgression takes place between the middle and the lower ones, where a competent seal caps the compartment below. All pressure gradients in the wet sand packages show positive slopes of 0.46 psi/ft (Gulf of Mexico regional hydrostatic gradient).

PPG MWE versus D using SCF. Using the conventional

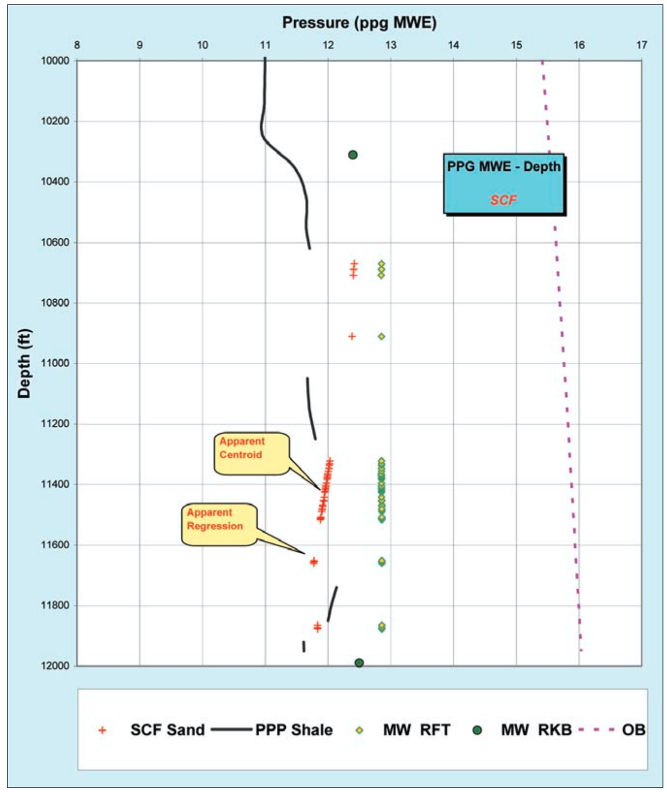

Figure 5. *Pressure-depth (EB 602 #1) in ppg MWE using the standard conversion factor.*

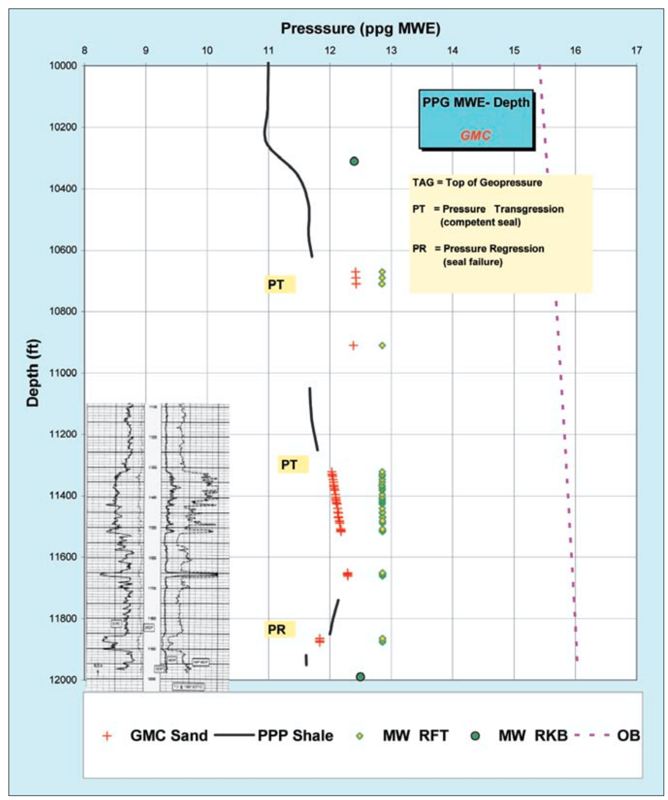

Figure 6. *Pressure plot (EB 602 #1) in ppg MWE versus depth applying the new GMC. The figure focuses on compartmentalization in pay zones and below.*

0.052 conversion factor has substantially altered the pore pressure profile (Figure 2). The pressure expressed in mud weight equivalent (SCF sand), in the permeable zones, shows a negative slope. This gives a false indication that the mud weight needed to exert the formation pressure decreases with depth.

Using this plot gives the artificial impression of the presence of the centroid effect. However, the centroid phenomenon cannot be recognized in a single well; it can be observed only by correlating multiple wells on a basin scale. Moreover, this plot shows an apparent pressure regression in each of the reservoir type sands in the geopressured system.

PPG MWE versus D using GMC. The geologically based modeling (Figure 3) successfully simulates the actual measurement in MWE and rectifies the pore pressure and sealing capacities profiles. The results of this method concur with the P-D plot interpretations and the mud log observations. The well was drilled with overbalanced mud (± 1 ppg). An increase in background gas was noticed at 13 940-13 970 ft where pressure transgression took place between the seal and the upper compartment. Moreover, nutplug sweep was frequently used to control mud loss below depth 17 000 ft where pore pressure shows a regression envelope.

Pay sands. Well 1 in East Breaks (offshore Louisiana) Block 602 (Nansen Field) was drilled by Kerr McGee to a TD of 11 990 ft. Several RFTs were taken in the pay and wet zones. This well exhibits the benefits of using GMC instead of SCF in pay zones.

P-D plot expressed in psi versus depth. The plot shows three distinct compartments (Figure 4). The upper wet one (10 670-10 910 ft) shows a higher value (PP psi sand) than the predicted pore pressure (PPP psi shale) in the top seal (pressure transgression). The middle pay zone (11 322-11 516 ft) is in communication with the pay zone at 11 650-11 660 ft. The lower wet zone at 11 850-11 900 ft shows a weak pressure regression on both the measured and the predicted pore pressure profiles. The proximity of the PP differential in the shale and sand beds to the mud weight pressure resulted in a stable borehole during drilling. Caliper shows that borehole was in relatively good shape. Furthermore, the slope on the pay zone RFTs shows a positive trend of light crude of specific gravity of 0.85 g/cc (API 28-30º).

PPG MWE versus depth using SCF. RFTs in the oil-bearing reservoir (SCF sand) show a negative slope (Figure 5) in spite of the constant value of the mud weight from RFTs and at the Kelly bushing (MW RKB). This enlarged graphic plot, which covers the lower section of the well between 10 000 and 12 000 ft, shows a negative gradient. This does not agree with the natural laws, which simply states that PP in a single reservoir increases with depth. Additionally, apparent centroid and regression take place between the measured PP and predicted PP.

Furthermore, the plot shows the same PPG MWE values at the base of the pay zone and the lower wet zone. Conversely, the P-D shows a weak regression between the middle and lower compartments, either due to the presence of the water leg or seal failure.

PPG MWE versus depth using GMC. The plot (Figure 6) exhibits a similar result as the P-D plot. Three compartments are clearly shown with the positive gradient slope in the main reservoir compartment. A clear communication is taking place within the sand section between 11 322 and 11 660 ft. Moreover, the GMC results show the regression envelope, on both the measured and predicted pressure, at the lower wet sand.

Benefits of using GMC. Several advantages and benefits can be achieved by using GMC instead of SCF:

- Eliminating negative slopes on the measured pore pressure when RFTs show PP increase with depth.
- Calculating MWE that corresponds to the actual data.
- Helping establish the right calibration for pore pressure prediction using petrophysical properties (velocity, resistivity, porosity, density, etc.).
- Avoiding the incorrect assumption of some geopressure phenomena as centroid and regression.
- Giving a more accurate estimate of the difference between the drilling mud weight on the rig floor/ECD (equivalent circulating density) and the formation calculated MWE from RFTs.
- Foreseeing drilling surprises such as hard kicks, blow out, and loss of circulation.

Conclusion. Most pore pressure related drilling problems occur at the seal/reservoir interface zones. Therefore, the misrepresentation of the PP profile in the permeable beds using SCF can result in drilling surprises and unexpected losses. Furthermore, using PPG derived from SCF as a calibration tool for pore pressure prediction can lead to unrealistic pore pressure predictions in the shale (seals). Several apparent, but incorrect, geopressure behaviors can be seen on the PPG-D plots produced with SCF.

Conversely, GMC expresses the PPG MWE in sensible values that emulate the P-D plot. This new geologic-based modeling converts the measured subsurface geopressured profile to comprehensive values that matches the actual geopressure compartmentalization and seal effectiveness. Additionally, GMC can produce more accurate pore pressure prediction calibration in shale.

Suggested reading. "The equation for geopressure prediction from well logs" by Eaton (Society of Petroleum Engineers of AIME, paper SPE 5544). "Causes of disparity between predicted and measured pore pressure" by Shaker (*TLE*, 2002). TLE

Corresponding author: ~~ssshaker@compuserve.com~~