# Geopressure Centroid: Perception and Pitfalls

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**Summary**

The centroid concept (pressure lateral transform) assumes that there is a "center" or mid-point along a dipping sequence of seals and reservoirs where the pore pressure in both are in equilibrium. This observation can hold true in a specific geological setting where a sub-surface depositional system is still intact. Noteworthy, most of the exploration play concepts and prospects are usually subjected to structural deformation and breached seals. This leads to sub-surface communication between different reservoir quality beds and makes the centroid concept inapplicable. Pressure regression usually takes place where geological structural failure occurs. Some of the common pitfalls in observing and evaluating this phenomenon are:

- using a single bore hole,
- applying this concept in a hydrodynamic subsurface system,
- utilizing the PPG MWE (pound per gallon mud weight equivalent) – depth plot to exhibit and calculate the centroid effect.

**Introduction**

The centroid concept was introduced and discussed by Traugott 1997. Yardley and Swarbrick, 2000, referred to this phenomenon as lateral pressure transfer.

Most of the published centroid illustrations are exhibited in a single well P-D (pressure depth plot) expressed in PPG MW (pound per gallon mud weight equivalent). On these plots, using the combined pressure in psi and mud weight in the same axis led to great confusion among the pore pressure and geopressure analysts.

Bruce and Bowens, (2002), stated "Without question, expressing pore pressure in units of density is scientifically incorrect." Shaker, (2003), discussed rectifying the controversial conversion factors between pressure in pound per square inch and pound per gallon.

This abstract is a brief discussion about the fundamental geological setting that can create the pressure differential between the reservoir and top seal. Moreover, it includes a synopsis about the misleading interpretation of this phenomenon. Two case histories from the Gulf of Mexico discuss its viability and pitfall

**Concepts and Causes**

The term pore pressure can be confusing. Pore pressure is predicted in relatively impermeable beds (shale and clay) and measured in reservoir quality rocks (sand). However, in many occasions, there is not a direct link between the pressure in the sand and in the sandwiching shale. The relationship between predicted (PPP) and measured (MPP) pore pressure is often complicated and establishing the relationship involves analysis of the geologic setting and compaction disequilibrium gradient (Shaker, 2002).

In relatively clastic young sediments (Pleistocene-Tertiary), porosity indices (e.g., sonic slowness) are widely used to calculate PPP. Prior to drilling, seismic velocities are very helpful in estimated PPP in a proposed location.

In reservoir type rock (sand, sandstone, oolites, etc.), pore pressure is measured using wireline tools and drilling stem gauges. MPP in wet sand usually follows the main hydrostatic gradient in the region as long as the formation water density stays the same.

The age of the deposits, rate of sedimentation versus rate of accommodation, structural setting of a prospect and the fault plan lithology juxtaposition play a substantial role in pressure differential distribution in sand versus shale. On the structural crest, MPP usually exceeds predicted pore pressure (PPP). In the trough, it is vice versa.

The pore pressure profile in the sub surface is usually divided into two main segments. They are the normally pressured upper section and the compartmentalized geopressured lower section (Figure 1). The upper section is usually in communication with the seafloor offshore and groundwater onshore. Therefore, applying the centroid concept to evaluate the normally pressured segment is unsound. On the contrary, the compartmentalized geopressured system is confined and sealed from the free flow of the upper segment. The divergence between the pore pressure in the shale (PPP) and the pore pressure in the sand (MPP) is a consequence of compaction and the subsequent entrapment of the formation fluids in the geopressured section. MPP usually exhibits the hydrostatic gradient of the formation fluid (0.46 psi/ft in GOM) and progresses in a cascade fashion with depth (Figure 1). The shift from one envelope to a deeper one across the seal defines the sealing capacity of the interbedded shale. The pressure gradient in the shale tends to follow a higher gradient in the geopressured sealed system.

## Geopressure Centroid

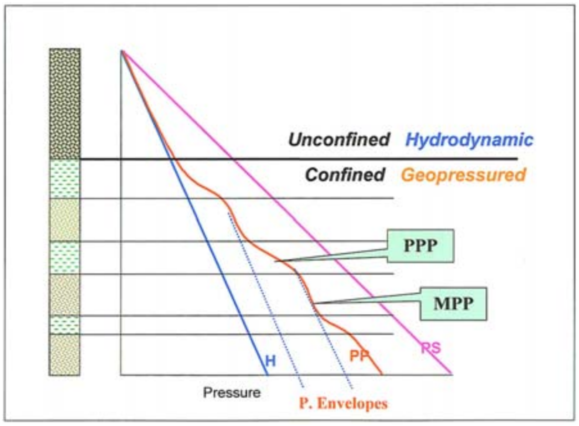


Figure 1: The two main subsurface pressure subdivisions. Hydrostatic, pore pressure, and principal stress as H, PP and PS respectively

The concept assumes the PPP and MPP are equal at a hypothetical point (centroid) on the structure. The sand subsurface pressure profile follows the hydrostatic gradient whereas seals follow a higher gradient. Updip from the centroid, MPP exceeds PPP at the shale-sand interface, depending on the structural gain, but downdip MPP exhibits lesser value than overlaying PPP (Figure 2).

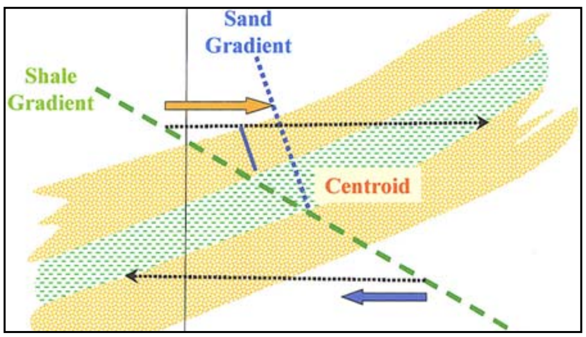


Figure 2: Differential pressure between PPP and and MPP due to the effect of the centroid along tilted beds interface

This phenomenon can also be explained by considering the overburden difference on high point versus low point on the structure. The low point exerts more compaction than the high point. Therefore, effective stress in the low point is more prone to exert higher pressure than the deposits in the high point. This leads to a higher pore pressure in the shale than the embedded sand, where effect stress is minimal. Because this phenomenon takes place in a geopressured static system, some of the geological setting can cause the excess pressure differential between sand and shale:

- stratigraphic traps of pinch out on salt and shale ridges (Fig. 3)
- four way closure
- sealed faulted three way closures

In the case of geological structural failure, mainly on fault surfaces where communication between permeable beds takes place, it is difficult to be accurate when applying the concept.

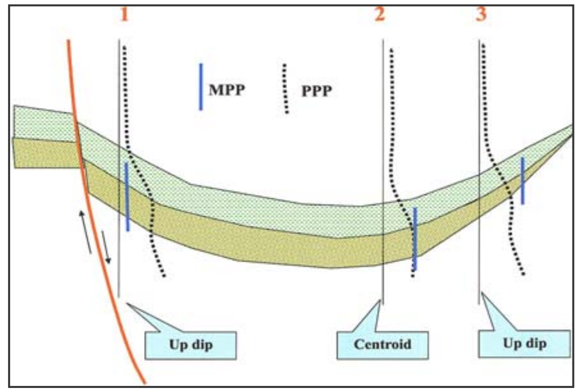


Figure 3: Sketch cross-section shows MPP higher than PPP in Well #3 and vice versa in Well #1 in spite of the fact that #3 and #1 are on a structurally higher position relative to the centroid

### Case Histories

The first example (Fig. 4) exhibits the necessity of using the geological building blocks in evaluating the "Centroid" phenomenon. In the east side of the basin (Macaroni), where sediments are pinching out on a salt ridge, an increase in MPP is indicated on the structural high. This is in spite of the west (Mt. Massive) showing a structural relief gain of 1500 feet. MPP is almost normally hydrostatic and extremely lower than the Macaroni location. This is due to the post sedimentation salt intrusion creating a gouge zone in the salt-sediment interface (Shaker 2004). Therefore, seal breach is responsible for making the MPP less relative to PPP on high structures.

The second case (Fig. 5) exhibits a comparison between two pressure plots for Keathley Canyon 255, Well #1. The MPP (RFT's) shows the pressure gradient in the wet sand beds following a positive slope (0.46 psi/ft.). On the other hand, the PPG-D plot, derived from using the standard conversion factor 0.52, resulted in a negative slope. This incorrectly illustrated an apparent centroid.

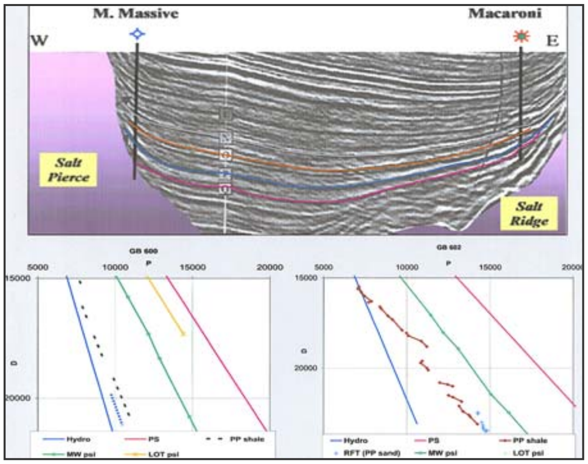


Figure 4: Seismic cross-section and pressure plots below illustrate the pressure differential as shown in Figure 3 south of the Auger Basin

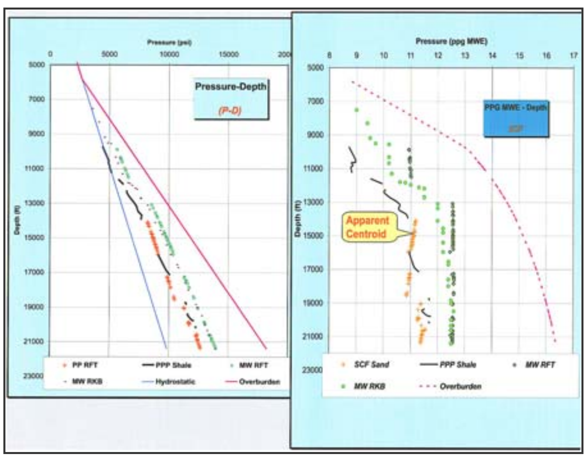


Figure 5: Shows the P-D plots in psi (left) and ppg (right) in Keathley Canyon 255 Well #1. Notice the apparent centroid on the ppg -D plot.

## Conclusions

The causes of disparity between the pore pressure in the sand and the surrounding shale is dictated by principal stress, permeability, structural setting and pressure decay. Since we are inclined to drill the high point on a prospect, the using the bona-fide "Centroid" concept explains the faster increase of the sand pore pressure relative to the predicted pressure in the shale climbing updip.

Building the geological blocks for pore pressure prediction is vital to foresee the MPP-PPP relationship. Evaluating the structure setting, including establishing the points of communication is strongly suggested before assuming that the centroid effect will take place. Moreover, using the standard conversion factor (0.52) to convert MPP in psi to ppg can display incorrectly several geopressure phenomena such as centroid and regression.

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