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Calibration of Geopressure Predictions using the Normal Compaction Trend: Perception and Pitfall

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The prediction of pore pressure (PP) is primarily established based on the divergence of the petrophysical measurements from the normal compaction trend. In the transition zone between the hydrostatically pressured and geopressured systems, formation water is expelled gradually from sediments due to pressure gradient drop from deeper to shallower depth. In this transition zone velocity, density and resistivity increase downward concurrent with the rate of dewatering process. *The Normal Compaction Trend* (NCT) represents the optimum fitted linear trend of these measured data in the low permeable beds in this transition zone. Inversely, in the geopressured system (where water is no longer capable of escaping) velocity, density, and resistivity measurements decrease in the low permeable beds.

In this study PP prediction and analyses, based on the effective stress models of numerous wildcats in the shelf and deep water in the Gulf of Mexico, reveal the significance of correctly defining the slope and extent of NCT.

Defining the NCT is an intricate process, which relies on several aspects. Stratigraphy and frequency of seals to reservoirs determine the slope and extent of NCT. In the outer-shelf paleo-environment a short extent and higher slope of NTC is usually associated with higher pore pressure gradient (PG). On the other hand, in the inner-shelf and deep water paleo-environments where NCT has a long extent and lower slopes a low PG is found. Moreover, structural setting has an immense impact on the slope and extent of the NTC slope. Structural high is usually associated with higher NCT slope (higher PG) and, conversely, structural low shows low NTC slope (lower PG).

The manual change of the slope on NCT leads to artificial alteration of the ratio of extrapolated normal petrophysical value to the actual observed petrophysical measurements, i.e. the value of $\Delta Tn / \Delta To$ at a specific depth. Therefore, swaying the NCT slope for the purpose of calibrating and fine tuning the predicted pressure compromises the effective stress – pore pressure transformation process. Breaking the NCT to several segments for the same purpose is a compromising adjustment process.

Moreover, because the structural setting of a lead or a prospect has a direct impact on the NCT's slope, and therefore assuming a common NCTC for the whole explored area is another pore pressure interpretation mishandling. Noteworthy, petrophysical data acquisition; processing and quality affect the outcome results and calculations.

Recommendations concluded from this study treat the NCT slope and extent as a constant predetermined geological component in the process of PP prediction – effective stress transformation models.

Background

Generic subsurface pore pressure profile is usually divided into three segments:

1. The shallow, upper, unconfined section is usually subject to free flow surface water. In an offshore setting, sea level fluctuation, brackish water encroachment, and sediment influx have a direct impact on the hydrostatic behavior of the normally pressured system (Fig. 1). This shallow unconsolidated sediment extends between the mud-line (sea floor) down to the depth where the compaction disequilibrium dewatering (CDD) process commences. Surface casing (drive pipes) is usually hammer-driven through this unconsolidated section.

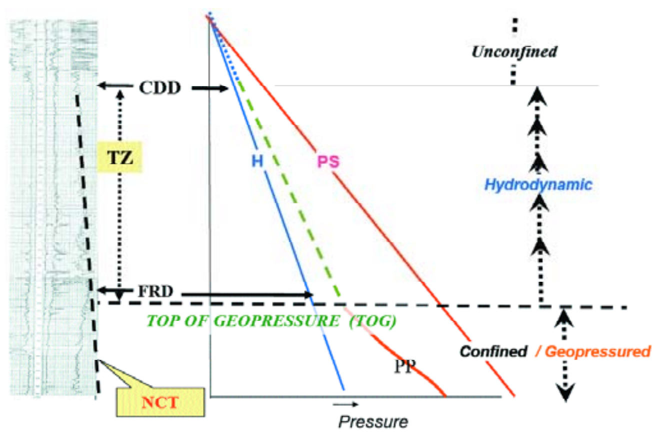

Figure 1. The three generic subsurface zones illustrated as unconfined, hydrodynamic, and confined geopressured. Hydrostatic, pore pressure, and principal stress are shown as H, PP, and PS, consecutively.

2. The middle hydrodynamic section, where upward dewatering process takes place between CDD down to a depth where stress and stratigraphy prevent fluid from breaching the top seal. The upward fluid flow in this section is a result of the gradual pressure gradient drop from the deep to the shallow layers. The depth where dewatering is seized is referred to as fluid retention depth (FRD) or top of geopressure (TOG). This *Transition Zone* (TZ) represents the phase where compaction disequilibrium is active between the lower confined geopressure and the unconfined upper sections. Drilling water flow hazards are common in this zone among young deep-water sediments. These hazards are usually initiated by the vertical flow generated by the pressure differential and permeability contrast in this zone.

3. The lower confined section is geopressured and the pore pressure gradient exceeds the hydrostatic. Although sand beds (reservoirs) show a hydrostatic pressure gradient, pressure gradient in shale (seals) is higher and tends to be

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analogous to the principal stress (PS) pressure gradient. Drilling in the geopressured section requires several casing points contingent on the subsurface drilling tolerance window (Shaker, 2002).

In the TZ, formation water is expelled gradually from sediments due to pressure gradient drop from deeper to shallower depth and consequently velocity, density and resistivity increase downward concurrent with the rate of dewatering process. The Normal Compaction Trend (NCT) represents the optimum fitted linear trend of these measured data in the low permeable beds. On the other hand, in the geopressured system (below TOG) where water is no longer capable of escaping, velocity, density, and resistivity measurements retreat in the seals.

The effective stress model of transforming the petrophysical measurement (e.g. sonic slowness) to pore pressure in the fine clastic (shale, mud, fine silt) beds is based on:

PP = PS – ES Terzaghi 1943

$PP_z = OB_z – (OB_z – Pn_z) * (\Delta Tn/\Delta To)^X$ Eaton 1975

Where:

PP = predicted pore pressure

PS = principal stress = Overburden (OB) in case of passive structure areas

ES = Effective stress

Z = depth to point of measurement

Pn = the normal pressure at depth Z

ΔTn = the assumed normal sonic slowness at depth Z (calculated from the NCT)

ΔTo = the observed (measured) sonic slowness at depth Z

X = PP transformation exponent (variable with age/basin location)

Therefore, the *keystone for this prediction practice* is the value of ΔTn /ΔTo, which is mainly conveyed as a result of establishing the slope on the NCT (fig. 2).

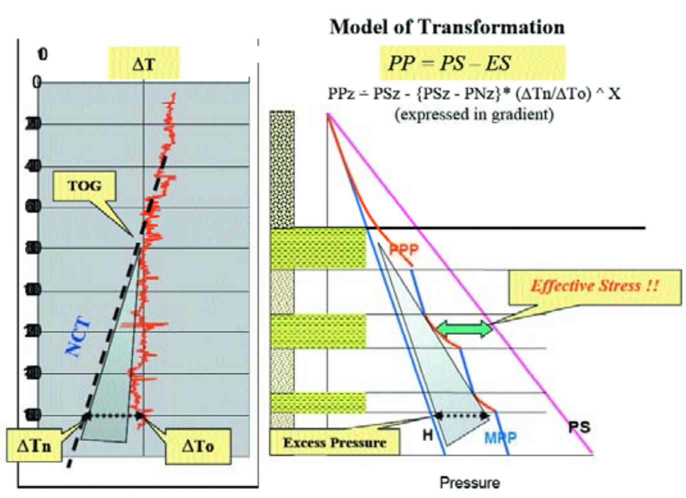

Figure 2. Shows the mathematical model that transforms the petrophysical properties (i.e. ΔT) to predicted pore pressure (PPP). Measured pore pressure expressed as MPP.

Geological aspects affect the slope and extent of NCT

Stratigraphy

Age: the PP profile in younger clastic sediments shows more active pressure build up and compartmentalization than older sediments that have been subjected to pressure decay over time. Therefore, NCT exhibits faster development and higher slope in younger basins, compared to older ones.

Stratification and the sand/shale: The ratio of reservoir beds (sand) to seal beds (shale) impacts the slope of NCT and the depth of the TOG. Delineation of NCT in a predominantly sandy lithology is incongruous. Shale picks on the SP/gamma and the corresponding R/DT have to be carefully chosen. For example, the sand rich middle-lower Miocene (Amph. B-Siph.D) section in

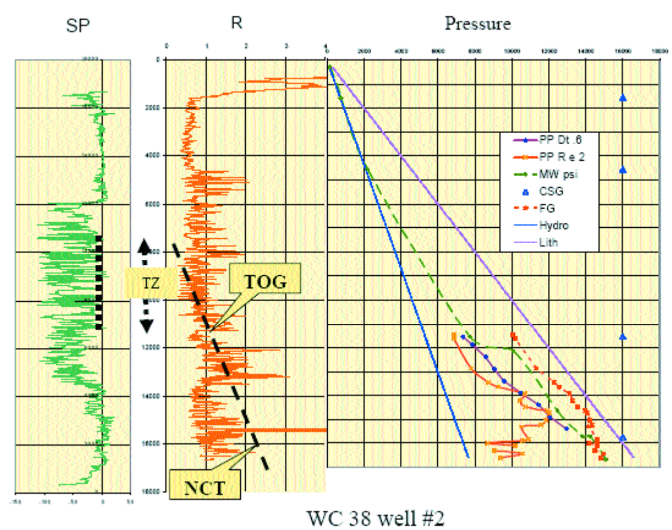

Figure 3. Shows an example of sand rich sequence in West Cameron 38, Well #2. A short TZ and higher slope NCT are observed.

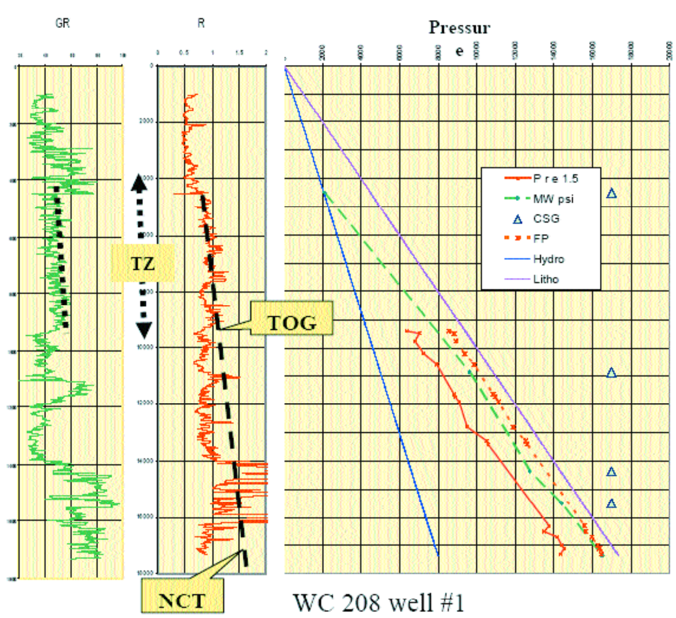

Figure 4. A shaley sequence in West Cameron 208, Well #1 where the TZ has a long extent and the NCT has gradual slope.

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