Project 1: Pore Pressure/Fracture Gradient and Wellbore Stability

- Field of Interest

The field of interest is located in the Gulf of Mexico within Mississippi Canyon (MC). The name of the field and well names have been changed for confidentiality reasons. The focus area for this study will be referred to as the Primary Template Area (PTA) (Figure 1).

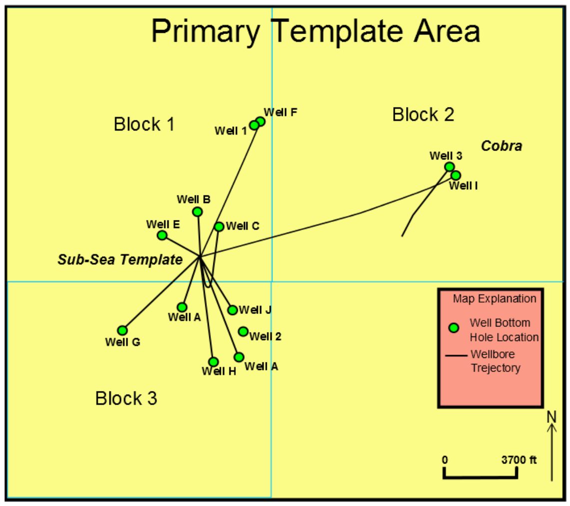

Figure 1: Map of PTA Field

The major geology present in the PTA is interbedded sandstone and shale. These sediments are Miocene to Pleistocene in age. A large salt intrusion lies in Block 2 roughly 4000ft below the seafloor. The edge of this salt diaper trends northwest-southeast and spans over the entire eastern half of Block 2. The presence of salt is the likely cause for much of the non-productive time while drilling wells in this block.

- Problems Encountered
  - Kicks
  - Lost Circulation
  - Uncertain Pore Pressures, most likely due to problems cause by salt intrusion
- Data Available
  - Petrophysical Logs: Density, Resistivity, Gamma Ray, Sonic, Seismic Interval Velocity
  - Leak Off Tests (LOTs)
  - Modular Dynamic Formation Testers (MDTs)

    - Known kicks and lost circulation events for calibration

- Objective
    - The goal of this project is to improve well design using multiple methods based on data available including logs and estimations. Primary task is to develop an operational window for each well by determining pore pressure, fracture gradient and shear failure gradient curves. The tasks required are outlined as follows:

<u>Project Tasks</u>

1) Determine Overburden Gradient from Gamma Ray Log

- Overburden Stress

Determining the overburden stress is the first step in any mud window prediction. The overburden is always the highest stress experienced by a wellbore. The bulk density measurements from the wellbore are applied to the following equation:

$$S = \rho_{bavg} g D \quad (1)$$

where S is the overburden stress, ρ_{bavg} is the average bulk density of the overlying sediments, g is the acceleration due to gravity 32.2 ft/s², and D is the depth in feet.

- The overburden gradient is obtained by the following equation:

$$\frac{\text{Cumulative Overburden Stress (psi)}}{0.052 * \text{Depth (ft)}} = \frac{S}{D} \quad (2)$$

where, S/D is the overburden gradient (ppg).

- The first step in obtaining the overburden is to determine the hydrostatic pressure caused by the overlying column of water. The following equation is applied:

Hydrostatic Pressure (psi) = Sea Water (ppg) x 0.052 x Water Depth (ft) (3)

For Gulf of Mexico, 8.6 ppg is the normal pore pressure of seawater.

Using Bulk Density Log to obtain Overburden Gradient

- Convert bulk density log from g/cc (grams per cubic centimeters) to ppg (pound per gallon)
- First determine the overburden stress in psi from the overlying column of water by applying **Eq. 3**.
- For each subsequent depth, convert bulk density log from ppg to psi (pound per square inch) to determine incremental difference between each data point
- Sum incremental differences to determine cumulative overburden stress at each depth
- Use **Eq. 2** to determine overburden gradient at each depth

2) Determine Pore Pressure Gradient from Resistivity Log

- Shale Points

The petrophysical methods for predicting pore pressure are based on shale resistivity and acoustic data. Thus, the "clean shale" formations encountered by the wellbore must be located. Clean shale are shale formations that have minimal silt or sand content. These are identified by the use of gamma ray log. The formations that have the highest API reading relative to the surrounding formations will be the considered clean shale. Some argue that there must be an exact API reading that designates a shale from a sand, but since logging tools can be calibrated differently for each log run, it is common practice to take a relative approach to picking shale points.

The complete shale points will be given by instructor before proceeding to the next part

- Eaton Pore Pressure from Resistivity

In 1975, Eaton built on the Hottman and Johnson method by developing empirical equations that could be used to predict magnitudes of abnormal pore pressure while considering a change in overburden gradient with depth. Eaton was able to formulate empirical relationships based on trial and error fitting of data and the implication of a NCTL. By also incorporating the petrophysical relationships to pore pressure previously established by previous studies.

$$\frac{p}{D} = \frac{S}{D} - \left[\frac{S}{D} - \left(\frac{p}{D}\right)_n\right]\left(\frac{R_o}{R_n}\right)^{1.20} \tag{4}$$

where $(p/D)_n$ is normal pore pressure gradient, S/D is the overburden gradient, R_o is measured resistivity in ohmm, and R_n is resistivity along the NCTL at the same depth. $(p/D)_n$ = 8.6 ppg in Gulf of Mexico

Using Resistivity Log and Overburden Gradient to determine Pore Pressure

- Plot gamma ray log and pick shale points, upon completion of this task receive DrillWorks Predict's correctly picked shale points
- Plot DrillWorks picked shale points and resistivity data on the same plot against depth
- Estimate the Normal Compaction Trend Line (NCTL) for resistivity by eyeballing a straight line that mimics the linear trend present within the first couple of thousand feet.
- Pick two coordinate points (x,y) one on either end of this line to add a trend line to chart
- Use equation of this trend line, y=mx + b to obtain coefficients. Coefficient 1 is always the opposite sign value of y-intercept (b), Coefficient 2 is the slope (m)
- Obtain the NCTL Resistivity values at each depth by adding each corresponding depth from resistivity log to coefficient 1 and then dividing this sum by coefficient 2
- Use **Eq. 4** to determine Eaton's pore pressure gradient at each depth on resistivity log

3) Determine Fracture Gradient from Resistivity Log

- Tensile Fracture Pressure

The widely accepted assumption that is made for predicting p_{imax}, or fracture pressure (p_f), is that the wellbore will already contain fractures, therefore the T_o term goes to zero. This simplifies the process by eliminating the need to know every formation's tensile strength prior to drilling a well. Matthews and Kelly (1967) derived a way to determine fracture pressure by first using Eq. (4) to find effective stress at a given. Once K is known, Eq (5) is applied to calculate the fracture pressure at the depth of interest.

$$p_f = K(S - p) + p \tag{5}$$

where K is the effective stress ratio, k = 0.8, S is overburden(ppg), p is pore pressure (ppg)

Using Resistivity Log and Overburden Gradient to determine Fracture Gradient

- Use **Eq. 5** to determine Matthews and Kelly's fracture gradient at each depth on resistivity log

4) Plot Overburden Gradient, Pore Pressure gradient, Fracture Gradient, and given mud weight on same graph

- Use provided leak off tests, modular dynamic formation tests, kicks and lost circulation data to further calibrate your window design

5) Determine Pore Pressure Gradient from Sonic Log

- Poisson's Ratio

Poisson's ratio is the ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force. Tensile deformation is considered positive and compressive deformation is considered negative. The definition of Poisson's ratio contains a minus sign so that normal materials have a positive ratio. Poisson's ratio, also called Poisson ratio or the Poisson coefficient, is usually represented as a lower case Greek nu, n.

It is possible to calculate Poisson's Ratio by using acoustic data from well logs.

$$\upsilon = \frac{0.5(DTS/DTC)^2 - 1}{(DTS/DTC)^2 - 1} \tag{6}$$

where DTS is shear wave slowness in μs/ft and DTC is compressional wave slowness in μs/ft.

- Eaton Pore Pressure from Acoustic

$$\frac{p}{D} = \frac{S}{D} - \left[\frac{S}{D} - \left(\frac{p}{D}\right)_n\right]\left(\frac{\Delta t_n}{\Delta t_o}\right)^{3.0} \tag{7}$$

where Δt_n is interval transit time in μs/ft along the NCTL and Δt_o is measured interval transit time at the same depth

7) Determine Pore Pressure Gradient from Seismic Data

- Eaton Pore Pressure from Interval Velocity

$$\frac{p}{D} = \frac{S}{D} - \left[\frac{S}{D} - \left(\frac{p}{D}\right)_n\right]\left(\frac{V\,\mathrm{int}_n}{V\,\mathrm{int}_o}\right)^{3.0} \tag{9}$$

where, $Vint_n$ is interval velocity in us/ft along the NCTL and $Vint_o$ is measured interval velocity at the same depth

Using Interval Velocity to determine Pore Pressure

- Convert given interval velocities from ft/s to us/ft (microsecond per foot)
- Determine the hyperbolic NCTL by following the same process as previously outlined for sonic data.
- Use **Eq. 9** to determine Eaton's pore pressure gradient at each depth on interval velocity data
- Plot overburden gradient, pore pressure gradient, fracture gradient, and given mud weight on same graph
    - Use provided leak off tests, modular dynamic formation tests, kicks and lost circulation data to further calibrate your window design