**Overburden, Pore Pressure and Fracture Pressure Overview**

**By George T Armistead, PE**

armisgt@yahoo.com

**Link to YouTube Video of this Presentation**
https://youtu.be/QmgFxC6HnZE

**Link to Copy of Notes on Google Drive**
https://drive.google.com/open?id=1kvfi8XOQOPCT5zsBdrHvGRBkEPPMV9Jd

**Link to Spreadsheet for Borehole Fracture Gradient Model**
https://drive.google.com/file/d/12kSEYhzFc654IxVS_Y5hWox60Q9kJX-I/view?usp=sharing

# Outline of Presentation

- **Importance and Introductory Application Questions**
- **Conversion Units and Natural Properties**
- **Porosity**
- **Overburden**
- **Pressure**
- **Pore Pressure**
- **Geological Layering**
- **Fracture Pressure**
- **Borehole Fracture Gradient Model**
- **Use of Borehole Fracture Gradient Model**
  - **Mitigating Loss of Returns and Selection of Casing Setting Depths**
  - **Casing Design Loads**
- **Review of Introductory Exercise Questions**
- **Final Application Exercise**

**Having knowledge of the fundamentals of the earth and rock strength is paramount to drilling. Drilling a well requires us to drill through the earth so it is incumbent on us to have a basic understanding of the earth and some principles.**

**The skill set to estimate <u>overburden, pore pressure, and fracture gradients</u> based on formation types is vital to choosing casing setting depths, determining casing pressure loads, testing and analyzing the integrity of barriers and doing well control assessments. Drilling engineers should be competent in obtaining reasonable estimates of these values for the areas that they are doing drilling engineering work.**

**Not all drilling engineers took geology courses on these topics as a result of their college majors or have received on the job training and experience in these aspects of well design. Understanding these principles are especially important for the more difficult drilling environments.**

**These topics are often avoided or not emphasized in many drilling training courses which if not understood can result in faulty well designs or execution plans.**

**<u>Introductory Application Questions</u> – Information required and needed for an understanding of the integrity of a well design:**

**A well is being planned in the Gulf of Mexico with no near surface salt. What would be the estimated shoe fracture gradient in a shale formation at 10,000' on the well being planned in 7,000' water depth (WD) in which the expected formation pore pressure is 9.5 pounds per gallon (PPG)? If a sand is present 50' below the casing shoe in the same pore pressure environment what would be the expected estimated sand fracture gradient?**

**If you don't consider yourself knowledgeable to assess the solution to these well design questions then this video and material should be able to aid and help you in your understanding.**

Natural Properties of Materials and Common Oilfield Conversion Factors and Units.

**These are givens and are a compilation of the properties of natural materials or unit conversions based on usage.**

**Volume**

- **Gallon** Drillers Pump Output (Gallons/Minute) Mud Weight (Pounds/Gallon)
- **Cubic Feet** Cementing (Cubic Feet of Slurry Volume)
- **Barrel** Production (Barrels/Day) Drillers - Hole Volume (Barrels)

**US oil & gas uses three different volumes in the same industry.** ☹

**Conversion Units and Natural Properties**

**Cubic Foot equals 7.48 Gallons**

**Barrell equals 42 Gallons or 5.615 Cubic Feet**

**Density equals Mass/Volume which is normally thought of as weight/volume in earth's gravitational field.**

**Specific Gravity (for solids and liquids) = Ratio of Density of substance / Density of Fresh Water**

**Specific Gravity of Fresh Water which is one of the most common substances and has been defined as a value of 1.0**
**FRESH WATER - Specific Gravity – SG – 1.0 Natural Density or Weight 8.33 pounds/gallon**

**SEA WATER - Density equals 8.6 pounds/gallon SG = 8.6/8.33 = 1.032**

**Formation Water - The density value of the salt water in the pore spaces generally used is a value of 9.0 pounds/gallon in the offshore environment which is higher than seawater due to the increased temperature and solubility of salt. SG = 9.0/8.33 = 1.08. The value in the middle of continents far away from the sea coast may be a value closer to 8.3 PPG which is the gradient of fresh water. It is based on the geological setting.**

**ROCK (Sand and Clay particles from a Driller's Perspective) SG ≈ 2.65**
**Density = 2.65 X 8.33 = 22 Pounds/Gallon**
**Rock particles are 2.65 times heavier than fresh water. This value will be used to approximate the weight of rock to evaluate our estimates utilized in well design.**

**SALT SG = 2.15 which equals 17.9 pounds/gallon Salt occurs commonly in nature in many structures and layers as 100% salt containing no porosity. Salt has a fairly high creep rate or ability to move based on increasing temperature.**

**CEMENT SG = 3.16 equals 26.3 pounds/gallon**

**STEEL SG = 7.86 equals 65.5 pounds/gallon**

**BRASS SG = 8.56 equals 71.3 pounds/gallon**

**POROSITY** - Pore space between grains of rock. It is normally expressed as a % of bulk volume of rock. It is represented by the following:

**Porosity = Pore Volume / Total Volume**

**Pore Volume = Total Volume – Rock Volume**

**Porosity = [ Total Volume – Rock Volume ] / Total Volume**

**Uppermost Limit – Cubic Packing**

**Application Exercise 1 – Calculate the porosity of our system containing a box with dimensions (width, length and height) of 4 times the radius of the spheres which contains 8 spheres in cubic packing (one sphere directly on top of another).**

**[Pause Video and Estimate the Porosity.]**

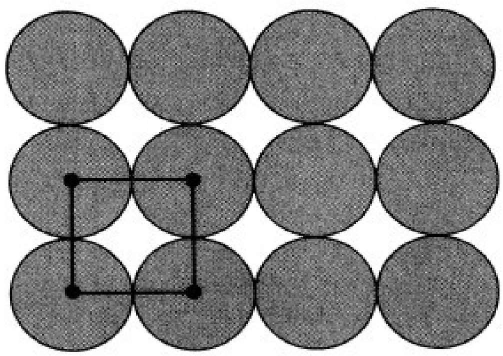
## Solution to Cubic Packing Exercise

**Porosity = Pore Space Volume / Total Volume**
**Pore Volume = Total Volume – Rock Volume**

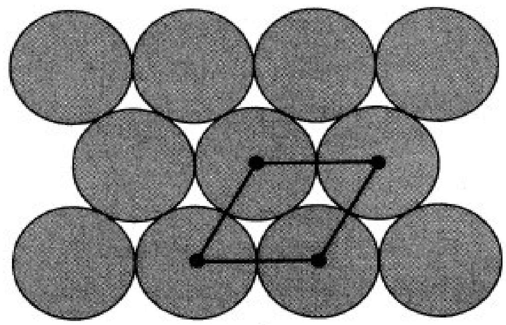
**Porosity =** $\dfrac{\text{Volume of Box} - \text{Volume of Spheres}}{\text{Volume of Box}}$

**Volume of Box = Width X Depth X Height =** $[4R]^3 = 64R^3$
**Volume of 8 Spheres =** $8 \times 4/3\pi R^3 = 33.51R^3$
**Porosity =** $[64R^3 - 33.51R^3] / 64R^3 = .476 = 47.6\%$

**Uppermost limit calculation.**



Cubic packing
(48% porosity)



Rhombohedral packing
(26% porosity)

**Cubic Packing doesn't occur in nature as it is not a natural position for a particle to land on top of another particle and remain stable. It is likely to fall into a more stable position between particles similar to the Rhombohedral Packing diagram on the right.**

**<u>Application Exercise 2</u> - Calculate the porosity of our rhombohedral system utilizing two layers of the diagram containing 8 spheres for rhombohedral packing**

**Porosity = [Total Volume of System] – Volume of Spheres] / [Total Volume of System]**
**Width and Depth remain at a dimension of 4R. Height is decreased to 4R X cos 45°**

**Pause Video and Estimate Porosity for Rhombohedral Packing**

## Rhombohedral Packing Solution

**Volume of Box = Width X Depth X Height =** $4R \times 4R \times 4R\cos 45 = 45.25R^3$
**Volume of 8 Spheres =** $8 \times 4/3\pi R^3 = 33.51R^3$

**Porosity =** $\dfrac{\text{Volume of Box} - \text{Volume of Spheres}}{\text{Volume of Box}}$

**Porosity =** $[45.25R^3 - 33.51R^3] / 45.25R^3 = .26 = 26\%$

**OVERBURDEN** The average bulk density of all the layers of sedimentary rock containing fluids and the ocean water from the surface down to a particular layer or depth of interest in the earth.

Application Exercise 3 – Calculate the Overburden of the sediments at the Mud Line in PPG given that the porosity is about 40% The sediments particles are not very compacted and widely spaced apart.

Calculating the overburden, we do so with two components for our system, sedimentary rock particles (SG = 2.65 = 22 PPG) and 9.0 PPG saltwater in the pore spaces (SG = 1.08).

Overburden (OB) = decimal volume rock X density rock + decimal volume saltwater X density saltwater Decimal volume saltwater + decimal volume rock = 1.0

OB = .4 X 9.0 + .6 X 22 = 16.8 Pound/Gallon (PPG) Driller's Unit

OB can be described in other ways such as Average Specific Gravity. For the same example our solution would be the following:

OB = .4 X 1.08 + .6 X 2.65 = 2.02 → 2.02 X 8.33 = 16.8 PPG

There are no correct units. Units must be consistent.

Driller's are interested in controlling the well and communicating instructions to rig site managers. Drillers usually calculate and work in terms of Pound Per Gallon of mud density.

Reservoir engineers and geologist who are interested in reservoir volume of oil or gas prefer % porosity. The example that we calculated is 40% porosity.

All wellbore information and estimates should be attained by selecting the best source of information and shift to less reliable sources of values as necessary.

Measured Data → Empirical Estimates → Educated Guess

- Overburden Density Logs, Offset Data, Empirical Equation, Experienced Estimate
- Pore Pressure (PP) Measured PP (kick, perforating, production BHP, DST), MW, Empirical (Pore Pressure Plot), Experienced Estimate (Scout Ticket of Offset Well Data)
- Fracture Gradients Measured, Offset Data, Empirical, Experienced Estimate

**Traugott Empirical Equation** **Empirical - Equation that Matches Measured Data**

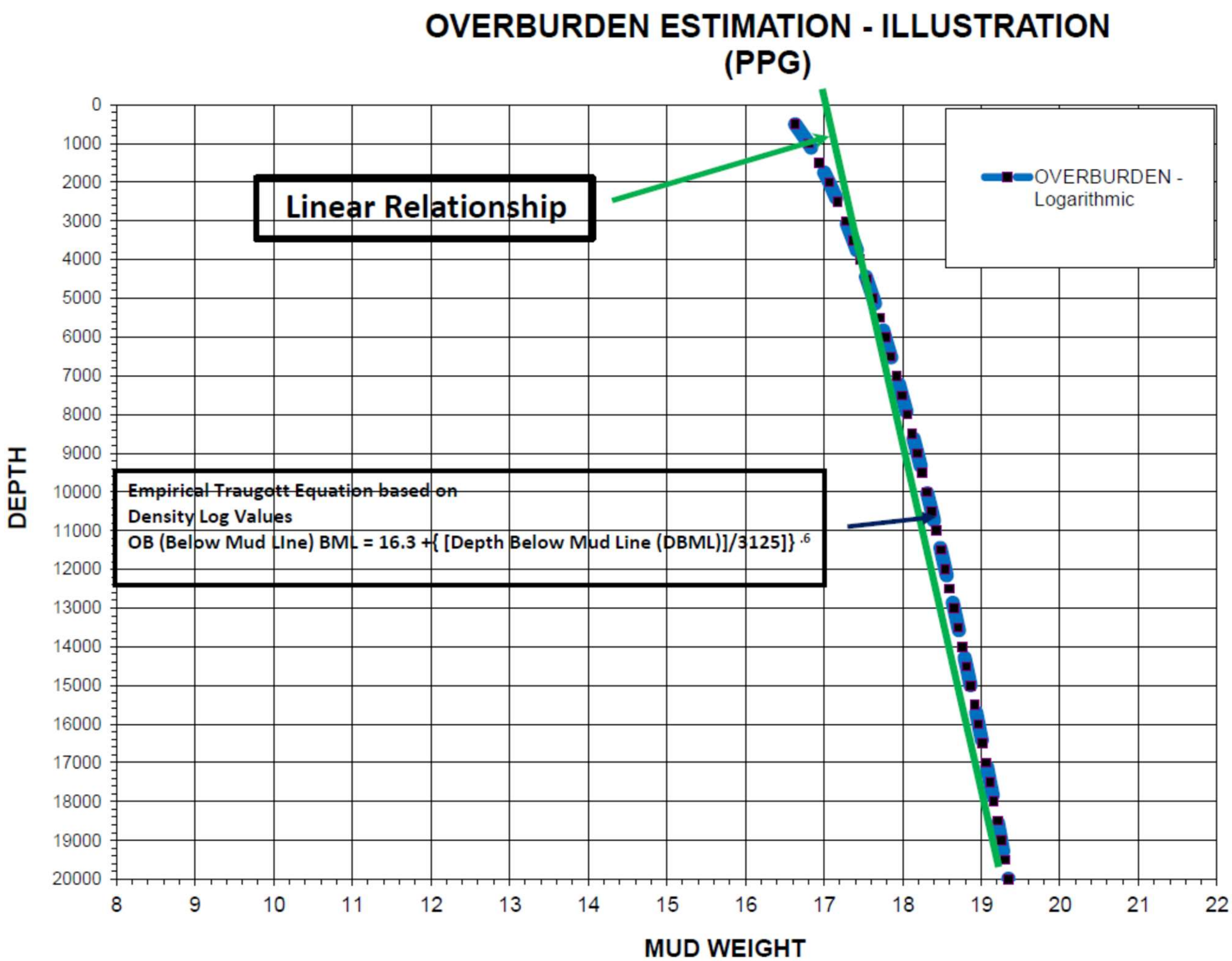
**$OB_{BML} = G_{SED} = 16.3 + ( D_{BML} / 3125 )^{.6}$** **$D_{BML}$ Depth ( feet ) BML**

**(Must be calibrated to specific operating areas)**

**Linear Estimate**

| | | |
|---|---|---|
| **5,000' BML** | **35% Porosity** | **$OB_{(BML)} = .35 \times 9.0 + .65 \times 22 = 17.5$ PPG** |
| ***10,000' BML*** | ***30% Porosity*** | ***$OB_{(BML)} = .30 \times 9.0 + .70 \times 22 = 18.1$ PPG*** |
| **15,000' BML** | **25% Porosity** | **$OB_{(BML)} = .25 \times 9.0 + .75 \times 22 = 18.7$ PPG** |
| **20,000' BML** | **20% Porosity** | **$OB_{(BML)} = .20 \times 9.0 + .80 \times 22 = 19.3$ PPG** |

# Traugott Versus Linear Comparison of Overburden



**Both of these overburden estimates are only the estimates of the sediments below the mud line (BML). The linear estimates correspond to the table above of approximations porosity for the overburden BML.**

**Porosity values in the earth are determined indirectly from bulk density. The values of bulk density are measured by logging tools and then we convert it into porosity from the relationship that bulk density is made up of porosity filled with brine of 9.0 PPG for an offshore environment and between 9.0 and 8.3 in the middle of continents. The remainder is rock with a density of 22 PPG. This relationship gives us the following equation with X being the decimal equivalent of porosity.**

**$X * 9.0 + ( 1 – X ) * 22 = \text{Bulk Density}_{PPG}$**

**Example: Bulk density is measured as 17.1 PPG at a particular depth in the well. What is the porosity?**

**$X * 9.0 + ( 1 – X ) * 22 = 17.1$ Solving for X we get .377 or 37.7 %**

**Since Overburden is estimated based on all layers to the surface when a location is offshore and water depth is applicable the overburden estimate must then be calculated in two steps.**

1. **The OB estimate is calculated for the sediments below the mud line.**
2. **The arithmetic average of the overburden BML along with the water depth and density are used to estimate the overall overburden.**

**Application Exercise 4: Calculate Overburden at 9,000' in 2,000' of water depth (WD) using the linear relationship for overburden BML.**

**Pause video and estimate value before analyzing solution.**

**Solution: For this example we have two overburden layers to consider made up of 7,000' of sediments BML and 2,000' WD containing 8.6 PPG seawater for a total depth of 9,000'.**

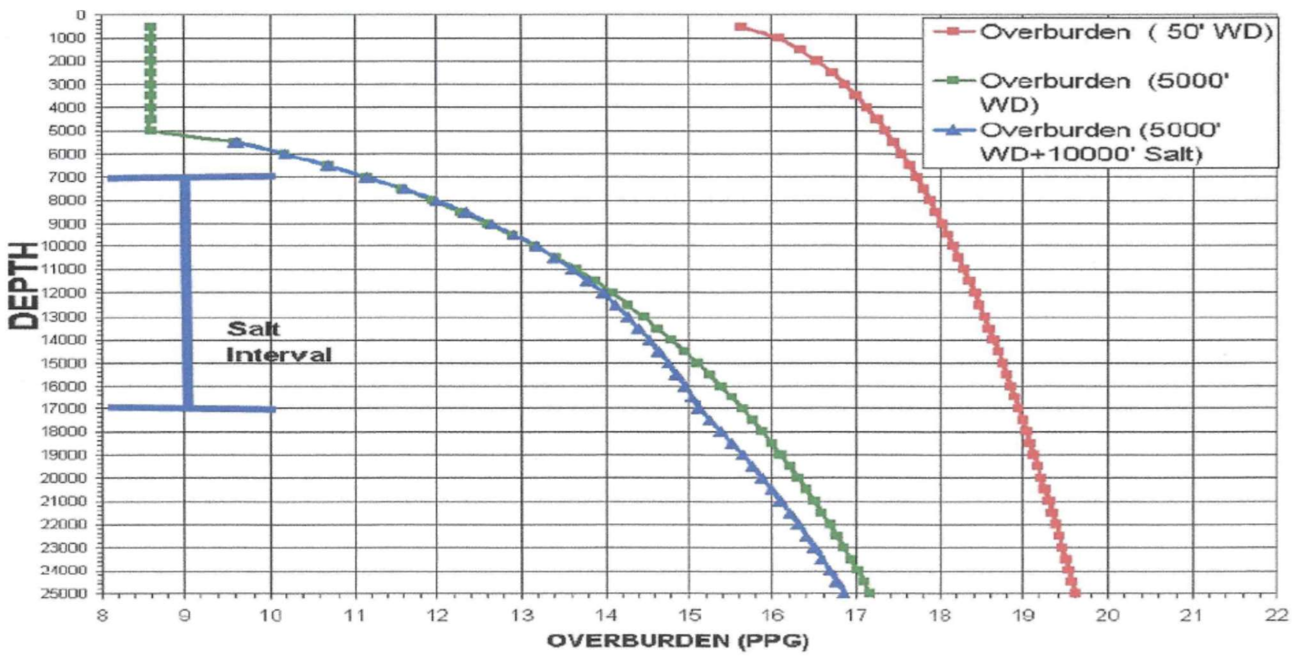
**Since we have 7,000' of sediments BML we can interpolate between 5,000' BML and 10,000' BML and therefore estimate porosity as being 33% from the table. This means that the average porosity for all of the sediments below the mud line is 33%. It does not mean that the porosity at 7,000' BML is 33%.**

1. **$OB_{(BML)} = .33 X 9.0 + .67 X 22 = 17.7$ PPG**
2. **Total OB = [ 17.7 X 7,000' + 8.6 X 2,000' ] / 9,000' = 15.7 PPG**

**The 2,000' WD reduces the overall overburden to a much lower level.**

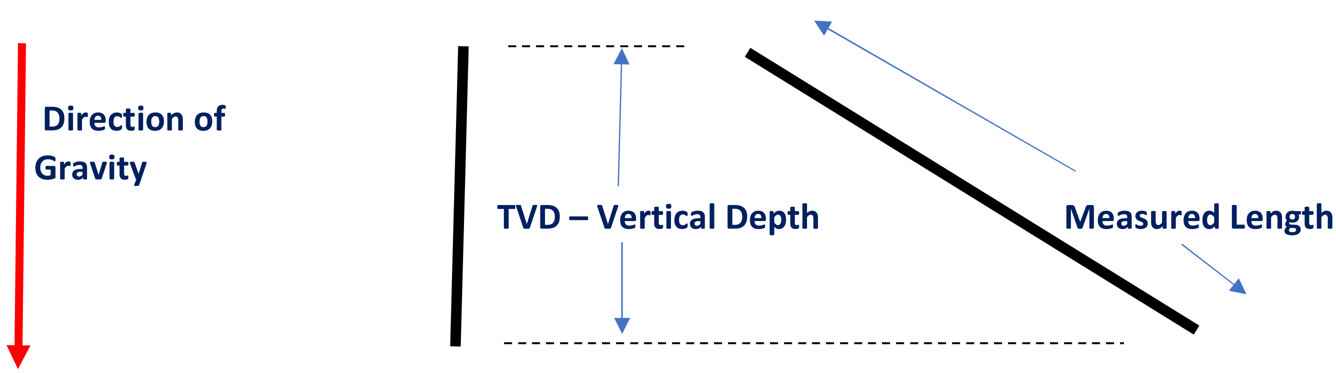
**Salt which has a SG of 2.15 or equivalent of 17.9 PPG can have a significant effect upon overburden estimates as well.**

**Overburden Illustration**




**Pressure – Force acting over a cross sectional area. Pressure can be thought of in several ways. For solids we generally think of pressure in terms of stress as force divided by area normally with the units of pounds / square inch or psi stress.**

**Pressure from a fluid acts equally in all directions. Hydrostatic pressure is a pressure resulting from the gravitational force. The direction of gravity is acting towards the center of the earth so any length or depth measurement must be the component of length towards the center of the earth as shown below. We normally use True Vertical Depth (TVD) in the drilling world as the length of the wellbore that is acting in the direction of gravity.**

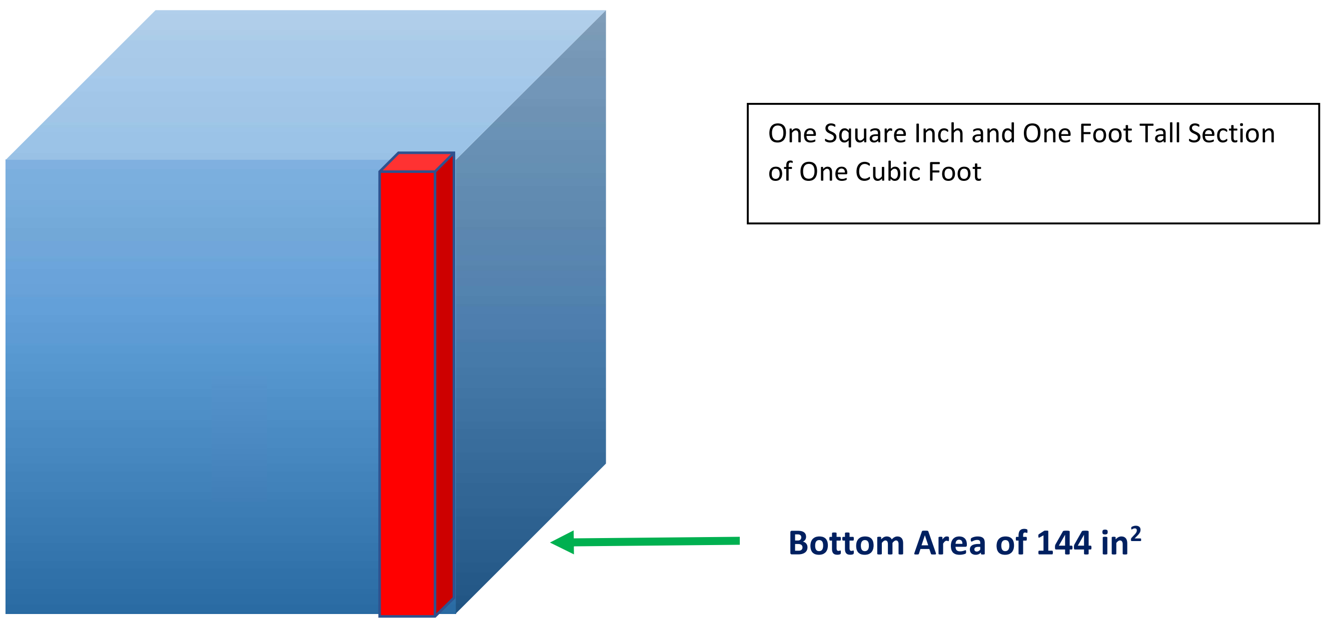


**Pressure = Force / Area = Weight / Area when our system is only the gravitational field**

**Cubic Foot = Each Dimension is 1'   (Width, Depth, Height)**

**Cubic Foot equals 7.48 Gallons**
**Bottom Area of Cubic Foot with sides of 12" X 12" = 144 $in^2$**

**Volume of 1 $in^2$ X 1' Tall Column of the Cubic Foot**
**7.48 Gallons Total / 144 $in^2$ = .052 gals / $in^2$-ft**




**<u>Pressure</u> = Force / Area = Weight of fluid in column / $in^2$**
**Using the column with 1 sq. in section X 1' tall with volume .052 gals / $in^2$-ft**

**The pressure calculation will then be the weight of the fluid in a 1 $in^2$ column however tall it is in TVD feet.**

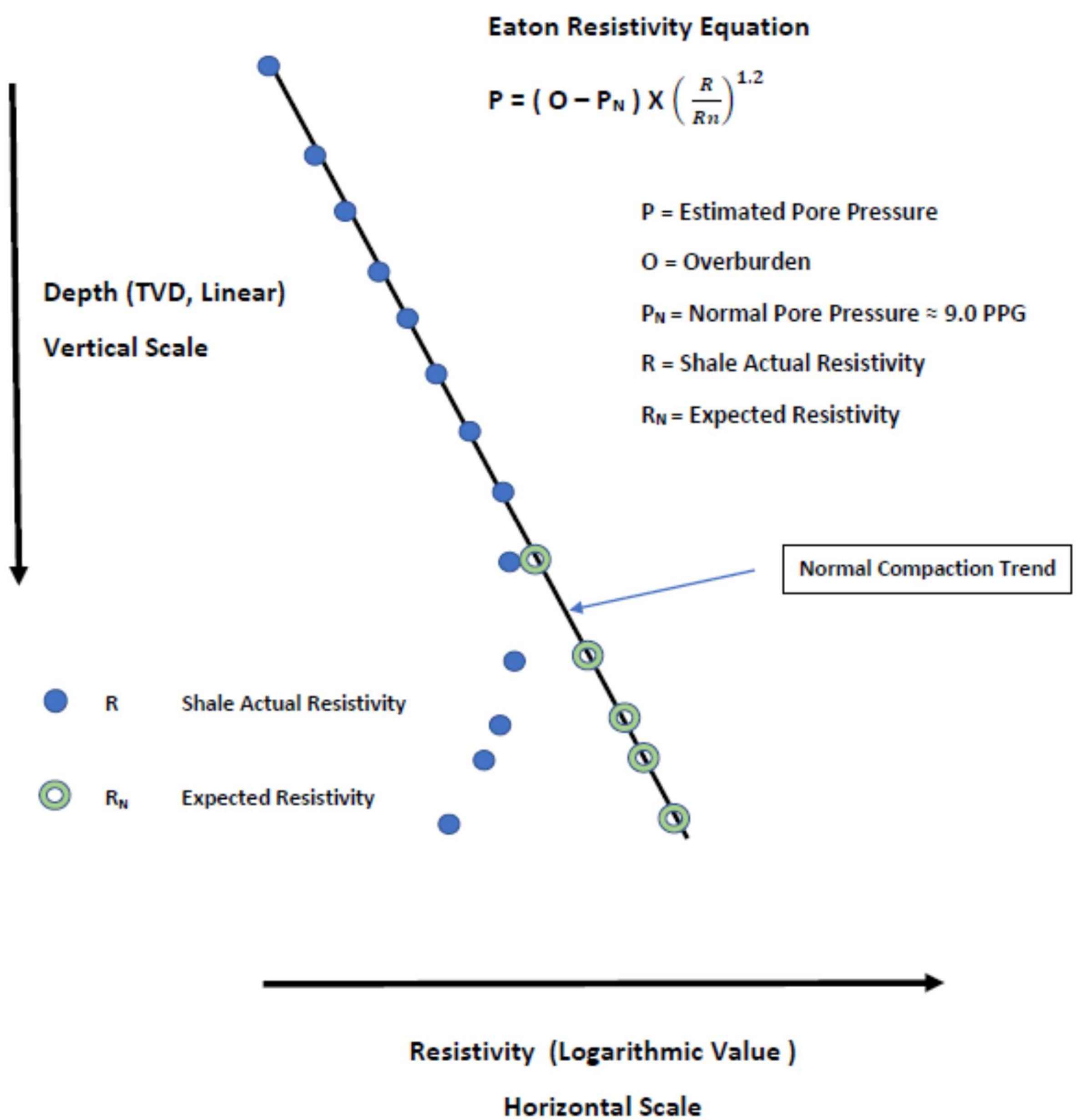
**<u>Pressure</u> = Weight/Area = .052 gal / $in^2$-ft X TVD Height $_{ft}$ X Density $_{pounds/gal}$ = psi**

**<u>PORE PRESSURE</u>** **The pressure within the pore spaces of the rocks within the earth.**

**Pore pressures are obtained from the best source of information to the least reliable source of information.**

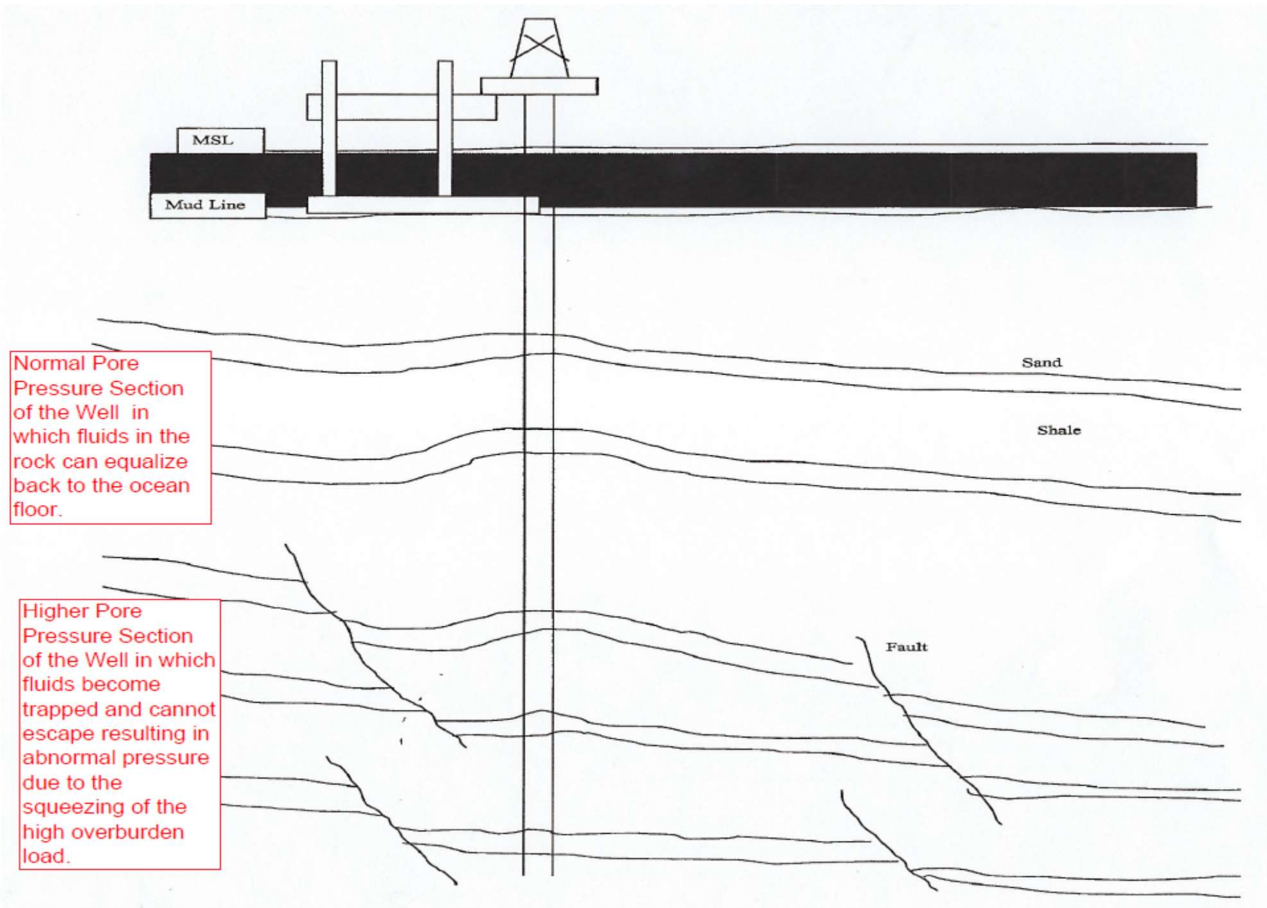
- **Actual pressure in existing well (kick, DST, perforating, production BHP)**
- **Assuming the drilling mud weight density is close to pore pressure**
- **Empirical method (pore pressure plot utilizing resistivity) Note: Only works well in a continuous depositional basin environment outboard of a continent containing sand and shale layering.**

**Eaton Resistivity Method for Pore Pressure Prediction Estimate**



**Sand and Shale layering takes place in a continuous depositional basin environment similar to the Gulf of Mexico in which all sediments are deposited downstream from the mouth of rivers like the Mississippi River. The layering is caused by very long climatic weather changes in rainfall (velocity and energy to move particles).**

## Geological Layering Illustration



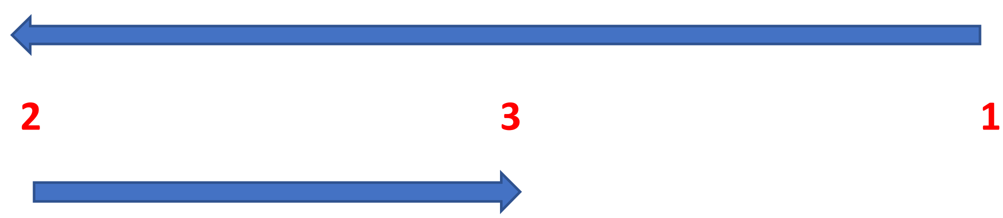

**A sand particle represented by the marble on the left is hard to transport whereas the coin on the right representative of clay particles has a very large surface area compared to its weight and is easy to transport.**

## SIGNIFICANCE

**Having an understanding of Overburden and Layering is nice information but why is it useful and important?**

**Everything related to well design and the risk management of a well is dependent upon an understanding of our drilling environment.**

- **Casing Setting Depths and Number of Strings**
- **Well Control Evaluation and Analysis**
- **Barrier Testing and Evaluation**
- **Casing Pressure Loads and Design**
- **Hole Cleaning Analysis**



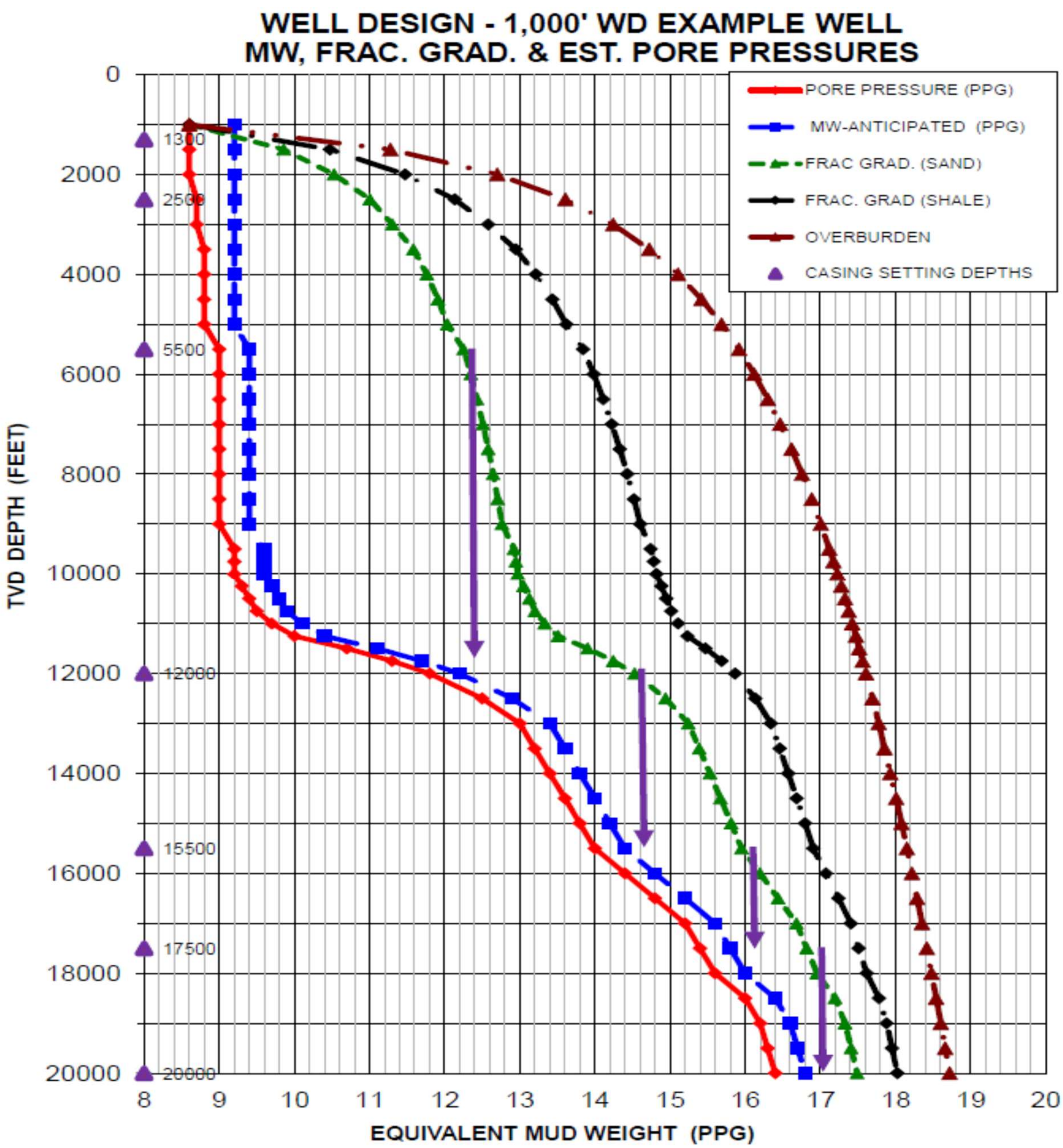

**PORE PRESSURE < FRACTURE GRADIENT < OVERBURDEN**

1. **We first calculate Overburden.**
2. **We then utilize Overburden to help us Estimate Pore Pressure**
3. **Using both Overburden and Pore Pressure we then estimate Fracture Gradient**

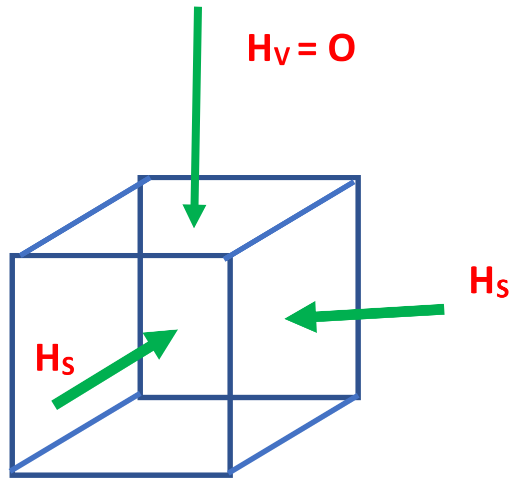
**<u>Fracture Pressure</u> – The lowest natural stress in the rock formation in which if exceeded the formation is likely to fail. There are two horizontal stresses which have a lower stress value than the one vertical stress equaling overburden.**

**WELLBORE DIAGRAM NEEDED FOR WELL PLANNING**

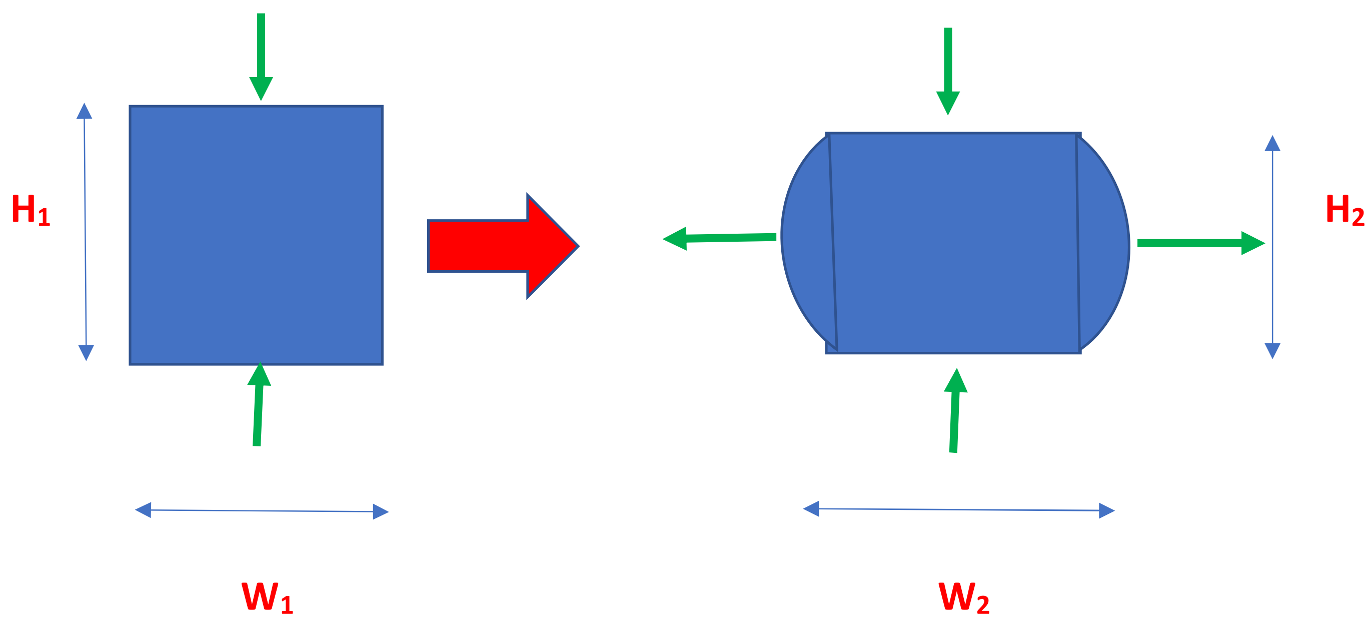
**BOREHOLE MODEL FOR WELL DESIGN**



**We cannot measure or estimate the horizontal stresses directly so we must first estimate the maximum stress which is overburden and use relationships to then estimate the horizontal stresses.**




**A vertical load from the overburden stress results in a horizontal stress in the formation rock.**




**A term that is used to describe this change in shape and resulting stress is <u>poisson's ratio</u>.**
**Poisson's Ratio = Horizontal Strain / Vertical Strain**

**Poisson's Ration = $(W_2 – W_1) / (H_1 – H_2)$**

**An increase in Poisson's Ratio results in a greater horizontal stress.**

**Poisson's Ratio of common materials.**

| | |
|---|---|
| **Steel** | **.3** |
| **Lead** | **.4** |
| **Rubber** | **.5** |
| **Silver** | **.37** |
| **Tungsten** | **.28** |
| **Clay** | **.4 - .49** |
| **Quartz** | **.17** |

**Overburden is the vertical stress at any depth of interest which is holding up every other layer above it. Overburden can be considered to made up of two components or forces equaling to the weight of all the layers above.**

**Pore Pressure - The pressure of the rock formation fluids that is acting in all directions including upwards.**

**Effective Stress (ES) – The stress of the rock particles pressing against one another. We don't measure ES directly but subtract the pore pressure from OB to obtain effective stress. ES = O – PP**

**Overburden = Effective Stress + Pore Pressure**

**OB = (O – PP) + PP**

**FP = ( Effective Stress ) * Rock Stress Coefficient + Pore Pressure**

**FP = ( Overburden – Pore Pressure ) * Rock Stress Coefficient + Pore Pressure**

**FP = ( O – P ) * K + P**

| | |
|---|---|
| **O = Overburden** | **Vertical Stress at Depth of Interest** |
| **K = Stress Coefficient** | **Ratio of Horizontal to Vertical Matrix Stress** |
| **P = Pore Pressure** | **Pressure within the pore spaces of formation** |

**Stress Coefficient varies with materials.**

**Stress Coefficient = Poisson's Ratio / ( 1 – Poisson's Ratio )**

**Stress Coefficient for pure quartz = .17 / ( 1 - .17 ) = .205**

**NOTE = Formation Rock is NOT a pure substance and contains a varying amount of void space based on porosity estimation.**

**Since for oil field use where we are not drilling pure material then we must use a modified value of Stress Coefficient in order to estimate our fracture gradients.**

**Personal Observations Around 1980**

- **Dr. Ben Eaton developed a methodology for estimation of shoe strength using the FP equation and shale material properties. There was not a strong industry understanding or consideration at the time for an alternative approach than designing wells based on shoe strength.**
- **Intermediate casing shoes at approximately 10,000' – 12,000' TVD were tested to Equivalent Mud Weights of 16.0 – 17.0 PPG and then mud returns were lost below the casing shoes when increased to 14.5 – 15.0 PPG.**
- **Surface Casing shoes at approximately 4,000' were tested to 14.5 PPG and then mud returns were lost when the mud was weighted up above approximately 13.0 PPG.**

**The above observations led me to the conclusion that the material differences between sand and shale have a substantial difference relating to fracture pressures. Hundreds of FP data points between 4,000' TVD and around 15,000' TVD after mud returns were lost were determined. The stress coefficients were then back calculated. These depths are mostly in the range of 20 – 25% porosity.** **FP = ( O – P ) * K + P**

**The resulting conclusion that best fit all the data collected in this depth range was to utilize a Stress Coefficient of .7 for Shale and a Stress Coefficient of .47 for Sands. These values are empirical values that fit data collected and cannot be derived.**

**Stress Coefficient = Poisson's Ratio / ( 1 – Poisson's Ratio )**

**Using the relationship Stress Coefficient equals Poisson's Ration / ( 1 – Poisson's Ratio ) then the Pseudo Poisson's Ratio for Shale would be .41 and a Pseudo Poisson's Ratio of .32 for Sands. Remember neither of these values are for pure substances in nature but can be thought of properties of a sponge containing porosity. The cleanliness of any sands and actual porosities would also have an effect upon actual fracture gradients.**

| Material | Stress Coefficient | Pseudo Poisson's Ratio |
|---|---|---|
| SHALE | .7 | .41 |
| SANDS | .47 | .32 |

**Assessing the observation below the intermediate casing shoe example at approximately 10,000' with an estimated pore pressure of 11.5 PPG:**

**Using an average porosity of 30 % for 10,000' in very shallow water.**

**OB = .3 X 9.0 + .7 X 22 = 18.1 PPG (Can also be determined from the graph on page 7)**

**Shale FG Estimate = ( O – P ) .7 + P = ( 18.1 – 11.5 ) X .7 + 11.5 = 16.1 which is close to the observed shoe test of the casing string set in a shale formation.**

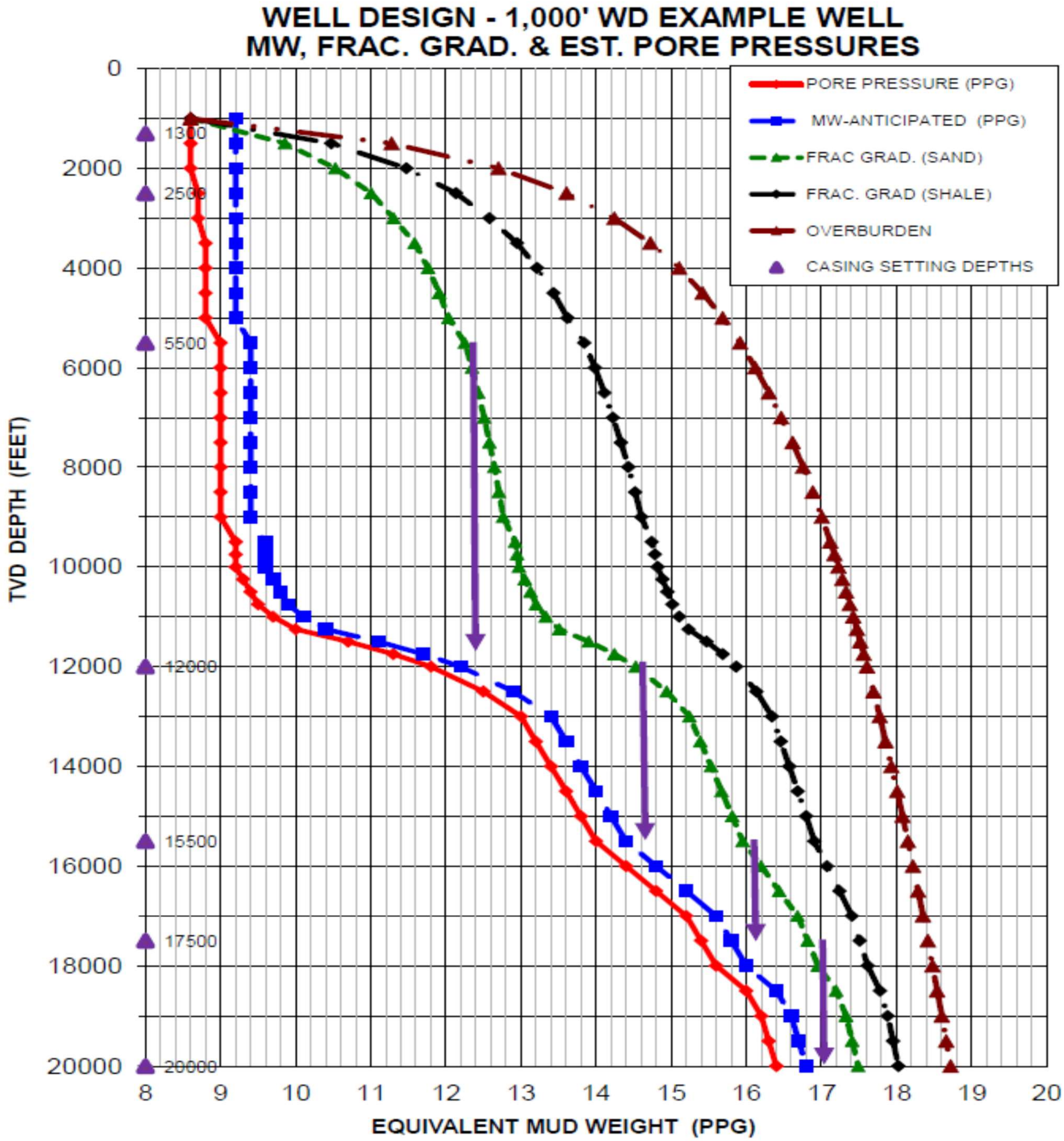
**The estimated sand FP using the FP equation and the Stress Coefficient for Sands of .47 we get the following:**

**Sand FG Estimate = (O – P ) .47 + P = ( 18.1 – 11.5 ) X .47 + 11.5 = 14.6 which also is the equivalent mud weight in which returns were lost below the casing shoe with a sand just beneath the casing shoe.**

**NOTHING IS WRONG**

**Calibration of the Stress Coefficient Values in each operating area should be done for the better estimating of FP's.**

## BOREHOLE FRACTURE GRADIENT MODEL




**You note looking at the chart that the sand fracture gradient at the surface casing shoe depth of 5,500' is about 1.5 PPG less than the shale fracture gradient at the same depth and NOTHING IS WRONG.**

**A well design based solely on shoe test probably is a flawed design since the shoe test may have been conducted in the strongest rock type.**

**Your actual casing setting depths may be adjusted based on your knowledge of the absence or presence of sand formations. The Fracture Gradient curve for sands does not apply if there are no sands present or known to be absent from a well section. The real well design challenge is to wrestle with the question of "how much do I really know about the geology and willing to accept the consequences".**

**Important concept in utilizing the Borehole Fracture Gradient Model.**

**In choosing casing depths and mitigating loss of returns you choose casing setting depths based on the sand fracture gradient curve to avoid losing returns.**

**When doing casing design load analysis, it is done using the shale fracture gradient curve which will provide the most robust casing design loads. No sands may be present below a particular casing shoe.**

**Pause Video and Estimate Solution Values of Introduction Exercise.**

**Application Exercise 5 Review Introduction Questions**

**For a well being planned in the Gulf of Mexico with no near surface salt what would be the estimated shoe fracture gradient in a shale formation at 10,000' on a well being planned in 7,000' water depth (WD) in which the expected formation pore pressure is 9.5 pounds per gallon (PPG)? If a sand is present 50' below the casing shoe in the same pore pressure environment what would be the expected sand fracture gradient?**

**<u>SOLUTION</u>:**

**Based on information given the depth of interest is 3,000' BML based on 10,000' depth of interest minus the water depth of 7,000'. Using the table on page 7 and interpolating between 40% porosity at ML and 35% at 5,000' BML we would estimate that the average porosity at 3,000' BML to be about 37%.**

**Using 37% porosity for the average porosity of the sediments BML we then calculate the overburden of the sediments below mud line based on the following:**

**OB = Overburden of sediments consist of 37% 9.0 PPG saltwater + 63% rock with a density of 22 PPG.**

**$OB_{BML}$ = .37 X 9.0 + .63 X 22 = 17.2 PPG** **<u>Overburden of Sediments BML</u>**

**Overburden at 10,000' can then be determined by calculating the arithmetic average between the two layers of 7,000' WD of 8.6 PPG seawater and the 3,000' sediments below mud line of average density of 17.2 PPG.**

**OB = ( 7,000' X 8.6 + 3,000' X 17.2 ) / 10,000' = 11.2 PPG**

**Shale FG = ( O – P ) X .7 + P = ( 11.2 – 9.5 ) X .7 + 9.5 = 10.7 PPG**

**Sand FG = ( O – P ) X .47 + P = ( 11.2 – 9.5 ) X .47 + 9.5 = 10.3 PPG**

## Application Exercise 6

**Analyze the scenario below to determine what was the cause of the problem.**

**Plans are made to deepen a well to 12,000’ located in the marsh of South Louisiana in a canal which has 9-5/8” casing set at 10,000’. It was drilled to this depth with 10.5 PPG mud and it was planned that the open hole section is to be drilled with 13.0 PPG mud. The barge rig is moved on to location and the well is successfully drilled to 12,000’ only requiring 10.5 PPG mud as no pressure transition was detected after drilling out the casing shoe. A 7” liner is successfully run and cemented utilizing 35% excess slurry with a 300’ liner lap up to 9,700’. The drill pipe is pulled out of the hole after running the liner and then the well is cleaned out to the top of the liner at 9,700’ encountering ratty cement at 9,350’ and then very hard cement on top of liner. The rig follows the completion procedure written at the beginning of the project to test the liner lap by pressurizing up on top of the liner to 2,100 psi and no leakoff in pressure occurs. Since the liner lap test is successful the rig then begins a displacement process to displace out the 10.5 PPG mud from the well with canal water prior to displacing the well over to 10.5 PPG brine completion fluid. About half way through the displacement process with the canal water the well begins to unload and the well is successfully shut in with 2,700 psi of casing pressure. The rig makes preparations to circulate out the well and once circulation begins on the choke the casing pressure drops to 0 and it is found that the drill string is stuck and packed off from solids with no ability to circulate.**

**What is the likely cause of the very difficult situation?**

Estimate OB at 10,000’

Using 30 % Average

OB = .3 X 9.0 + .7 X 22 = 18.1 PPG

Assuming PP = MW - .5 PPG

P = 10.5 - .5 = 10.0 PPG

9-5/8” Shoe FG = ( 18.1 – 10.0 ) .7 + 10.0 = 15.7 PPG

Barrier Test = 2100 PSI Over 10.5 PPG MW

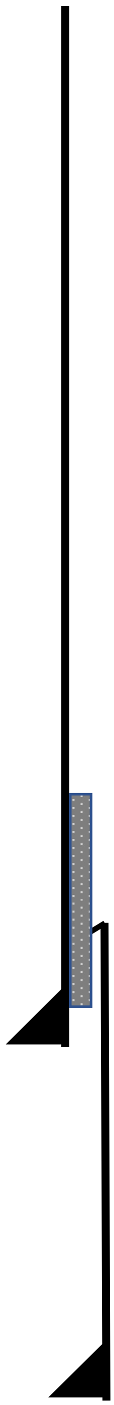
Equivalent MW = 2100 / (.052 X 10,000) + 10.5

EMW = 4.0 + 10.5 = 14.5 PPG

FG > EMW barrier test

What was accomplished with the liner lap barrier test?

**NOTHING** – The well may have held the 2100 psi even if it had not been cemented.



**TOC 9,350’**

**TOL 9,700’**

**9-5/8” Casing Shoe at 10,000’**
**MW = 10.5 PPG**

**Bottom of Liner (BOL) 12,000’**
**MW = 10.5 PPG**

**Always assess and understand your drilling environment in making all drilling decisions.**