Cloud Publications
International Journal of Advanced Earth Science and Engineering
2017, Volume 6, Issue 1, pp. 548-556
ISSN: 2320 – 3609, Crossref: 10.23953/cloud.ijaese.277

Case Study

Analysis of Pore Pressure - Predrill Tool in Operation Geology

Rakhi Arvind Pandey

Western offshore basin ONGC, Mumbai, Maharashtra, India

Publication Date: 10 June 2017

DOI: https://doi.org/10.23953/cloud.ijaese.277

Abstract Formation pressure plays an important parameter in the health of a borehole. In the oil field, pressure is commonly measured in pounds per square inch (psi). At the wellsite, we are typically concerned with the pressures throughout the circulating system. Study of Pore pressure or formation pressure makes a very important subject for the wellsite Geologists.

Keywords *Hydrostatic Pressure; Subnormal Pressure; Overburden Pressure; Pore Pressure*

1. Introduction

Pressure is defined as the force acting on a unit area. In the oil field, pressure is commonly measured in pounds per square inch (psi). At the wellsite, we are typically concerned with the pressures throughout the circulating system. We may need to know the pressure at a particular point in the wellbore (such as the casing shoe or a lost circulation zone) or we may want to know the total pressure required to pump a certain mud volume at a given rate. The different kinds of reservoir pressures which are usually encountered during the course of drilling are broadly divided into three main components (Figure 1):

- Hydrostatic or normal pressure,
- Overburden or load pressure and
- Formation or pore pressure.

1.1. Hydrostatic Pressure

The normal, predicted pressure for a given depth or the pressure exerted per unit area by a column of freshwater from sea level to a given depth.

1.2. Overburden Pressure

The overburden pressure at any point in the formation is that pressure exerted by the total weight of the overlying formations. In other words the overburden pressure is the result of the combined weight of the formation matrix plus the fluids in the pore spaces, overlying the formation of interest. The calculation and establishing of overburden pressure is the first step in analysis of wellbore pressures because all other pressures quantities are consequent upon the overburden.

The overburden pressure can be expressed as the hydrostatic head of all materials overlying a certain point or depth of interest. So,

$$Sp = g\ \rho_b\ H$$

Where- Sp = Overburden Pressure, G = Gravity value, ρ_b = Average Density, H = Height of the column

1.3. Formation Fluid Pressure

Clastic rocks are composed of matrix, cementing material and pore spaces. These spaces are occupied by fluids that will constitute hydrostatic columns depending on the effectiveness of vertical communication. This vertical communication may be to the surface, the water table, or to permeability barrier of some kind, such as closure fault or salt bed. This pore fluids pressures constitutes the pore pressures. The overburden load is suppurated at a particular depth of interest by the pore pressure at that depth and the vertical component of matrix stress.

2. Types of Formation Pressure

The formation pore pressure is defined as the pressure acting upon fluids in the pore space of the formation; fluid can be oil or water and also gas in the pore space. Pressure expressed either in pound/inch^2, atmosphere or kg/cm^2 or psi/ft. there are three types of formation/pore pressures which are present in the sediments.

2.1. Normal Pressure

The pressure exerted by the column of water extending from any given level to the surface. Normal formation pressure gradient ranges from 0.433 psi/ft to 0.465 psi/ft or 1.0 gm/cc - 1.08 gm/ cc.

Overall pressure detection and prediction are very helpful while preparing mud, lowering casing, to prevent mud losses and lost circulation and also guiding for prevent kick or major blowout. Pressure can be defined by following equations;

$$P_H = g \times p \times h$$

Where, P_H = hydrostatic pressure, g = gravity value, p = avg. fluid density, h = height of the column.

2.2. Subnormal Pressure

Subnormal pressures are those pressures, which are less than the hydrostatic pressure. Hydrostatic gradient is less than 0.433 psi/ft or 1 gm/cc. In the Indian sub-continent, subnormal pressure occur in various places, both offshore and onshore, in carbonate as well as clastic reservoirs. It may occur due to following situations.

- Erosion,
- Depletion of reservoir,
- Artesian condition,
- Tectonic set up,
- Precipitation,
- Temperature change etc.

2.3. Overpressure (abnormal pressure)

Abnormal pressures are those pressures which are greater than the hydrostatic pressure. Pressure gradient is more than 0.465 psi/ft than the formation is said to have abnormal high pressure or overpressure. Overpressure is common in areas with rapid deposition, especially of younger sediments or in tectonically stressed areas or folded belts areas.

2.3.1. *Origin of Abnormal High Pressure Zones*

The causes for development of overpressure have been discussed by Hubert and Rubey (1959) [1]. The various phenomena for occurrence of overpressure are described below; these all phenomena can be divided into three major heads which are (Figure 2)

1) Sedimentological overpressure,
2) Structural overpressure and
3) Overpressure due to chemical or physical phenomena etc.

3. Why do we need to know pore pressure

Prediction of Pore pressure and Fracture pressure prior to drilling minimizes cost and risks associated with drillings. "Half the cost of high value wells comes from uncertainty; a large percentage of the uncertainty comes from pore-pressure and geo mechanics related issues". In case of economic viability the prediction is very helpful and it minimizes cost of the wells to be drilled. Hence basic understandings of the Formation pore pressures parameters are very much needed. There is no control over Pore Pressure Gradients, or Fracture gradients, and these are often largely unknown before drilling. It occurs nearly in all sedimentary basins; correct prediction not only reduces drilling costs substantially but also prevents many hazards which may result in well kicks, blow outs and other potential well complications, which may otherwise lead to the loss or abandonment of the well. Figure 3 shows a yearly NPT (non-productive time) of Western offshore Basin (shallow) rig during the period of (01-04-2007 to 31-3-2008). The Pie diagram shows nearly 77% Productive Time and 23% Non-Productive Time. Out of 23% NPT more than 60% rig time loss are due to complications. Such complications could be related to Pore Pressure or well bore stability i.e. Geo-dynamic and are considered to be avoidable, and 40% are non-avoidable including repair job, waiting on weather and man & materials.

3.1. Well site overpressure indicators

In the wellsite from the following change one can identify the overpressure zones. During drilling if the Rate of Penetration / Gas / "Splintery" Shale cuttings / Volume of Shale cuttings / Flowline temperature / Chlorides / Shale travel time increases or d-exponent / Shale Density / Resistivity decreases then it shows that any overpressure zone is present beneath the surface which is drilling now [2]. The standpipe pressure and pump rate exhibit changes in down hole conditions and may consequently be utilized to determine loss of overbalance. It should be observable that any of the following parameters indirectly related to the kick situation are also indicators. The various wellsite pressure indicators are used during drilling are listed in the Table 1:

Table 1: *Shows Wellsite (During Drilling) pressure indicator*

Pressure Indicator	Change In Value	Reason For Change
Drill rate	Increases	Formation is under compacted, differential pressure at the bit approaches zero.
D – Exponent	Decreases	Reflecting overall increased formation drill ability.
Total gas	Increases	Reflects greater volumes of in situ gas.
Background gas	Increases	Greater volumes of in situ gas, loss of overbalance.
Fill	Increases	Hole instability.
Flowline density	Decreases	As overbalance is lost, formation fluid contaminates drilling fluid.
Flowline viscosity	Increases	Formation fluid is often hotter, containing mineral hardness, causing mud flocculation.
Flowline salinity	Increases	The more highly saline formation fluid enters wellbore as overbalance is diminished.
Shale density	Decreases	Reflects under compaction in an Overpressured environment.
Cuttings shape, size	Increases	Reflects hole instability less gouging of formation presence of cavings.
Flowline temperature	Increases	Overpressured zones, possessing greater than normal pore fluid, act as thermal insulators.

4. Prediction of pore pressure at depth

Pore pressure prediction can be done by direct as well as indirect methods. Mud weight used during drilling against a permeable zone gives a clue about the pore pressure. Direct measurement of pore pressure of permeable zone is also possible by using variety of commercially available technologies. Geophysical data are also use for measurement of pore pressure. Seismic reflection data are used for the prediction of pore pressure before drilling the well. This is very important for the areas where high pore pressure is recorded and proper planning of drilling is required.

4.1. Pore Pressure Indicator

All pore pressure estimation methods are based on the premise that pore pressure influences compaction - dependent shale properties such as porosity, density, sonic velocity, and resistivity [2]. Any wireline or geophysical measurement that is sensitive to Pore pressure will be referred to as a Pore Pressure Indicator. The main Pore pressure indicators are summarized in Table 2.

Table 2: *Pore pressure indicators*

Before Drilling	Seismic Velocities
During Drilling	ROP(Normalized Rate Of Penetration), MWD, Pit Levels, Mud Gas (Drill gas, Connection gas, Trip gas, Pumps-off gas, C2/C3 ratio etc.), Mud Density, Cutting's Shape & size, LWD Resistivity, DT, Density, Formation Temperature (Formation temperature is usually inferred from circulating temperature or flowline temperature) Drilling Events Such as kick, influx, loss. Mud Chlorides (Background Chlorides, Trip Chlorides)
Post Drilling	a)Resistivity b)Sonic c)Density / Neutron, Measure direct pressure information i.e. Wireline formation tests. Drill stem tests, Well Seismic Checks (VSP, Checkshots etc.)

5. Case Study

Tapti Daman block in Bombay Offshore basin of India is a Tertiary clastic sub basin formed at junction of the Cambay and Narmada rifts and contains a sedimentary thickness in excess of 5000m. This block comprises of homoclinal area (Saurastra homocline and Eastern homocline) and number of ENE-WSW trending lows (Daman low, Purna low and Navsari low). The basin is divided into two areas Tapti in the north and Daman in the South The deeper Panna Formation in Tapti-Daman block consist of syn-rift and post rift sediments is predominantly argillaceous and represents the major source rock. Extensive Exploration in this area has revealed the structural and combination type entrapment of hydrocarbon in the clastic reservoirs of Daman (Late Oligocene) and Mahuva (Early Oligocene) Formation. Daman Formation consists of sandstone-shale alterations with a few coal lenticles and Mahuva Formation consists of dominantly shale with thin limestone bands and occasional sandstone stringers. The north south vertical pressure profile constructed from sonic trends reveals that the top of overpressure cuts across stratigraphic boundaries and is seen to rising towards the southern part of the block. The top of maturation is seen to be generally above the high pressured compartment. The pressure mechanism appears to be dominantly compaction disequilibrium [3].

The candidate well is drilled with objective of exploring hydrocarbon potential of carbonates within Panna formation and sands within Mahuva and Daman formation. The target depth of well was 4550m and water depth was 23m [4].

5.1. Methodology for prediction of predrill pore pressure and fracture gradient

From the well log data, Pore Pressure Gradient and Fracture Gradient have been calculated as described in the flow chart. (Figure 4)

The Predrill prediction of Pore pressure and fracture gradient for this well is carried out with the help of nearby well data and seismic survey study. In WOB, ONGC this study is estimated using **"Drillworks Software**" [5] [6]. The Figure 5 shows the study for this well.

1) The overpressure zone starts from Mahuva formation.
2) Pore pressure gradient is higher than the overburden gradient.
3) Observed gain at 3300, 3400 & 3800 m while drilling with near balance mud weight.
4) The maximum allowable mud weight between PP and FG is very narrow thus in such condition very challenging for safe drilling.
5) The well was drilled with hydrostatic + more than 100% mud hydrostatic and maximum BHT recorded 356°F (Log Header).

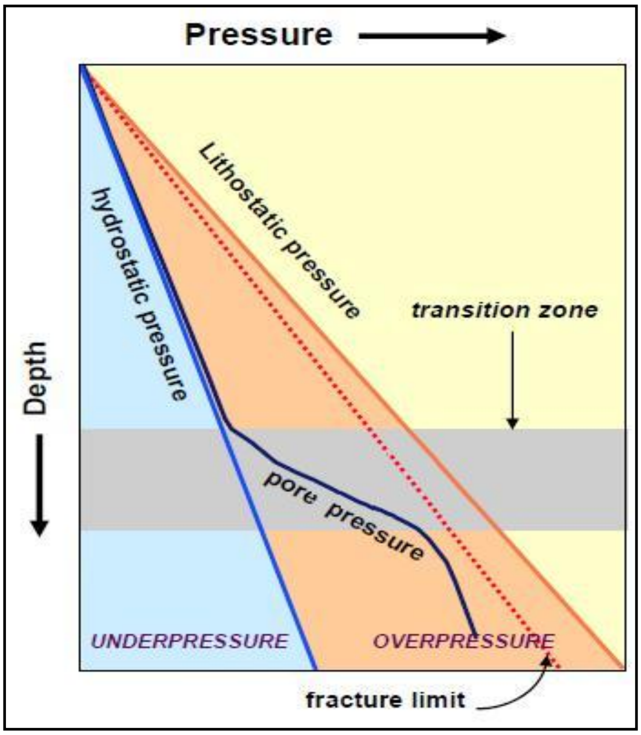

Figure 1: *Shows Pressure v/s Depth relationship, Hydrostatic, Pore pressure curve, Overburden curve (Lithostatic) pressure etc. (Source - Presentation by Nader C. Dutta, May-2005, Mumbai)*

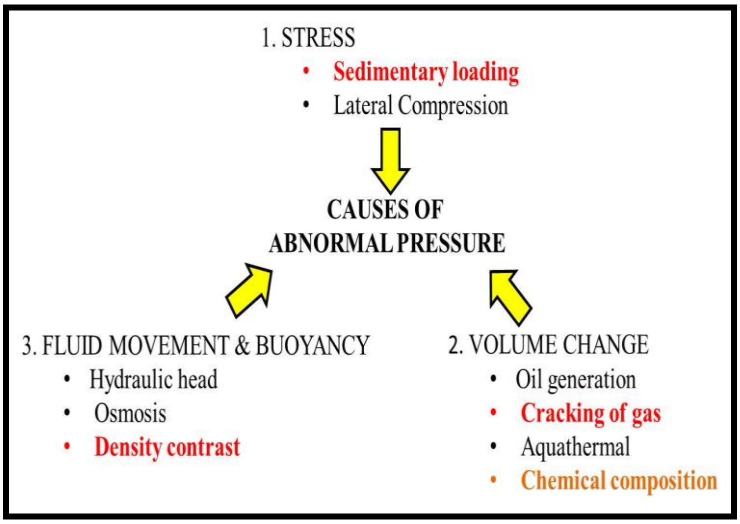

Figure 2: *Shows the causes of Abnormal Pressures*

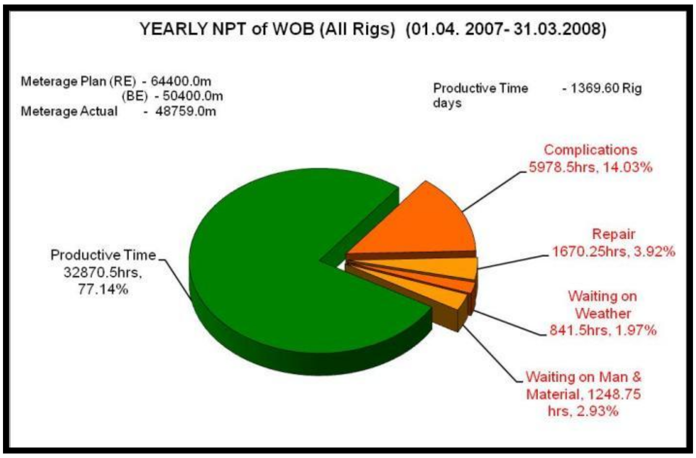

Figure 3: *Yearly NPT of WOB (Source ONGC reports, 2007-2008)*

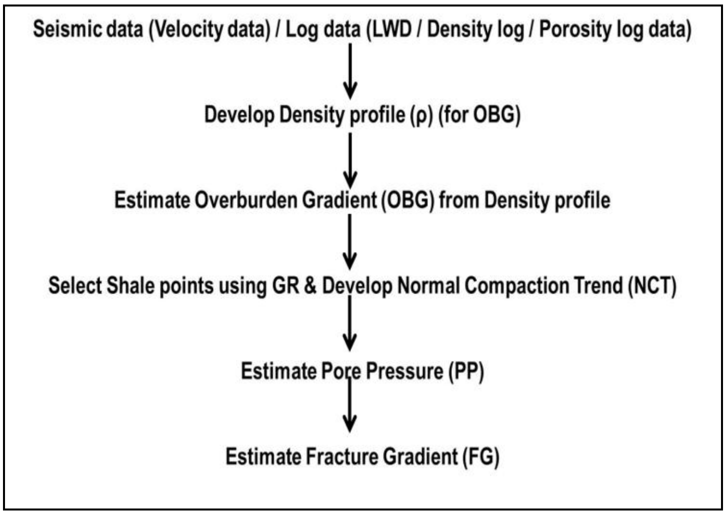

Figure 4: *Pore Pressure and Fracture Gradient Estimation [4]*

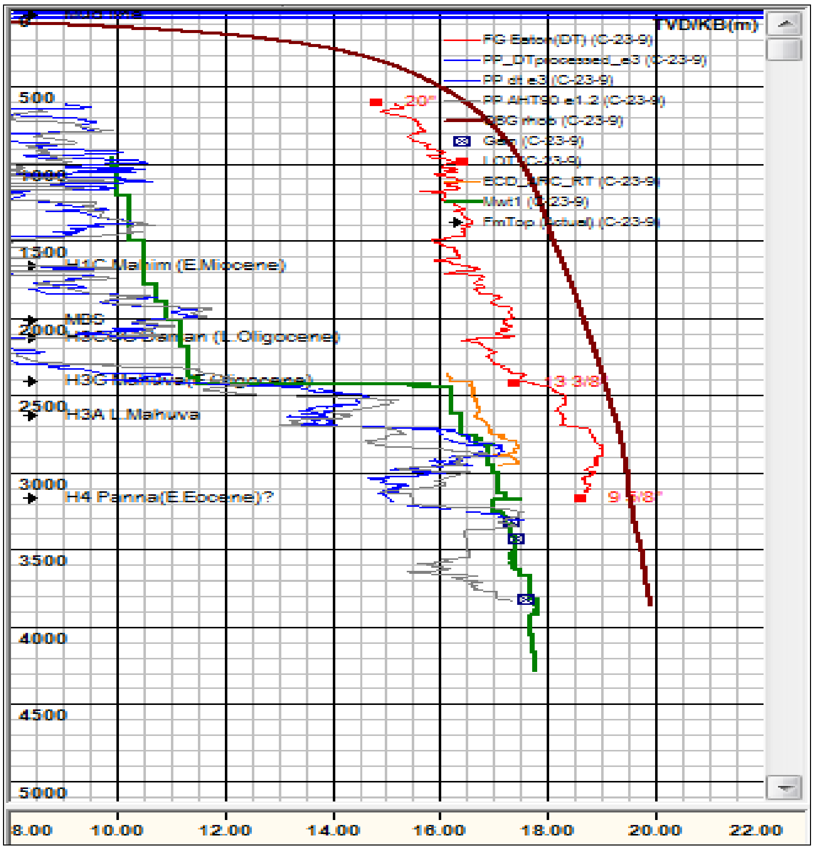

Figure 5: *Shows the final summary of Pore Pressure estimation*

6. Conclusion

Formation pressure, rock stress and sediment compaction is caused by the overburden load and tectonic stresses. Before drilling, during drilling and after drilling of the wellbore, proper evaluation of pore pressure is very important as every stage of the well drilling provide the useful insight about the formation pressure. Theoretical pore pressure model is fundamental approach for determination of formation fluid pressure of the formation. Compaction disequilibrium is the primary mechanism for generation of overpressure. By using the calibrated well log from the drilled wellbore Pore pressure can be accurately obtained.

References

[1] Hubbert, M.K., Rubey, W.W.: Role of fluid pressures in mechanics of overthrust faulting. I. Geol. Soc. Am. Bull. 70, 115-166 (1959)

[2] Applied Drilling Technology – Wellsite Manual, ONGC – India.

[3] Manas K. Chakrabarti, Ashesh R. Desai: Tapti-Daman block of Bombay Offshore, India – A possible site for Tight Gas Reservoir, ONGC, WOB, Mumbai, India.

[4] Well completion report of well-2 (actual name modified). Geological operation group ONGC, Mumbai. Unpublished report. (2015)

[5] Knowledge System Part I, Drillworks Predict. – Linda Mudrock.

[6] Paul, S., Chhatterjee, R., Kundan, A.: Estimation of Pore Pressure and Fracture Gradient from Well Logs: A theoretical analysis of techniques in use: 16th Annual India Oil & Gas Review Summit & International Exhibition, September 10-11, Mumbai, India. (2009)