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Pore Pressure: Causes, Methods of Determination and their Limitations

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Summary

During the early stages of the Ormen Lange slope stability evaluations it became apparent that the potential for excess pore pressure in critical soil formations was key in explaining the failure of the relatively flat submarine slopes of the original topography. A pore pressure measurement and monitoring program was needed. An accurate estimation of formation pore-pressure plays an important role in safe and economic drilling for overpressured sediments. Pore pressure within formation determines the mud weight required to build a balancing fluid pressure in the downhole. Fracturing of the formation or well blow-out may take place due to insufficient knowledge of subsurface geology and formation pressures depending upon the too high or too low mud weight. High pore pressures or overpressures have been observed at drilling sites all over the world in both land and offshore.

Introduction

Pore pressure is defined as the pressure acting on the fluids in the pore spaces of the rock. Depending upon the magnitude of the pore pressure, it can be classified into three types viz. normal, abnormal and subnormal. Depending upon whether the pore pressure is equal to, greater than or less than the hydrostatic pressure at the given depth. Determination of pore pressure can be done in two ways, pre-drilling and post drilling. Pre-drilling techniques consists of the seismic operations whereas the post drilling techniques can be classified into three categories. Firstly, the mud logging methods which includes measurements of drilling parameters and evaluation of drill cuttings gas levels at surface. Secondly, Measurement While Drilling, logging while drilling and wireline logging methods and lastly, the direct methods which includes DST, production tests and RFT.

Causes of Abnormal Pore Pressure

Abnormal pore pressure is developed as a result of a combination of geological, geochemical, geophysical and mechanical processes. These causes may be summarized under:

- Depositional Effects
- Diagenetic Processes
- Tectonic Effects
- Structural Causes; and
- Thermodynamic Effects.

1) Depositional Effects

1.1 Undercompaction of shales Undercompaction of sediments is the process whereby abnormal pore pressure is developed as a result of a disruption of the balance between rate of sedimentation of clays and the rate of expulsion of the pore fluids as the clays compact with burial.

1.2 Deposition of evaporites The deposition of evaporites can create high abnormal pore pressures in the surrounding zones with the pore pressure approaching the overburden gradient. When salt is deposited, the pore fluids in the underlying formations cannot escape and therefore become trapped and abnormally pressured.

1.3 Diagenetic Process With increasing pressure and temperature, sediments undergo a process of chemical and physical changes collectively known as diagenesis. Diagenesis is the alteration of sediments and their constituent minerals during post depositional compaction. Diagenetic processes include the formation of new minerals, recrystallisation and lithification. Diagenesis may result in volume changes and water generation

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which if occurring in a seabed environment may lead to both abnormal or sub-normal pore pressure.

1.4 Tectonic Effects Tectonic activity can result in the development of abnormal pore pressure as a result of a variety of mechanisms including: folding, faulting, uplift and salt diaparism.

1.5 Structural Causes

1.5.1 Reservoir Structure Abnormal pore pressure can exist in both horizontal and non-horizontal reservoir structures which contain pore fluids of differing densities i.e. water, oil and gas. Examples of structures in which this may occur are lenticular reservoirs, dipping reservoirs and anticlinal reservoirs. In dipping reservoirs, formation pressures which are normal in the deepest water zone of the reservoir, will be transmitted to the updip part of the structure.

1.5.2 Piezometric Fluid Level

1.5.3 Thermodynamic Processes

Methods of Determination

Pre-drilling Estimations

Pre-drilling estimation of pore pressure is done by seismic methods which are helpful in identifying the overpressured zones in the subsurface. Pore pressure estimation from seismic velocity data is a multidisciplinary subject that requires thorough knowledge of seismic data processing as well as an understanding of rock physics. The key parameters for pore pressure prediction are P-wave (Vp) and S-wave (Vs) velocities. All methods take advantage of the fact that sonic velocities depend on the effective pressure, and hence the pore pressure. The relation between effective pressure and velocity depends heavily on the texture and mineral composition of the rock. For instance, for unconsolidated sandstones, the P-wave velocities vary significantly with effective pressure (Domenico1977). The mechanism thought to be important here is the strengthening of grain contacts with increasing effective pressure. When applying external load to unconsolidated sand, the contact between the individual grains becomes stronger. Thus, the stiffness of the sand is increased. This leads to an increase in P-wave velocity. Thus, this leads to reduction in seismic wave velocity and hence an increase in acoustic impedance.

As per Hottman and Johnson (1965), empirical correlation of velocity ratios versus expected pressure gradient or mud weight is essential for the quantitative pore pressure evaluation. In all velocity-based methods, developmental of normal compaction curves plays critical role in overpressure estimations and limits the uncertainty of the prediction. Hottman and Johnson method work well where the offset well data is readily available, but in the wildcat planning the development of normal compaction will determine the uncertainty in pore pressure estimation. Hydrostatic pressure is defined as the pressure exerted by a column of water at any given point in that column, when water is at rest. It is the pressure due to the density and vertical height of the column which exerts force in all directions perpendicular to the contacting surface (Bourgoyne 1991). Mathematically, it can be expressed as a product of fluid density, height of the fluid column, and acceleration due to gravity.

By the time-depth conversions (Pennebaker1968), formations depths having different acoustic impedance can be found. From the interval travel time data, formation interval density was found by the following formula (ENI 1999)

Notable pore pressure prediction methods are Hottman and Johnson, equivalent depth Eaton's (1975) and Bowers (1995) methods. The first prediction approach by Hottman and Johnson (1965) method is still used in the industry due to its preciseness in pore pressure prediction. This method utilises calibrated sonic log velocities from offset well data and estimates the pore pressure for the proposed drilling location by linear regression.

Eaton's method (Eaton1975) approximates the effective vertical stress with ratio of sonic log velocities and resistivity values.

Post-drilling Estimations

As discussed earlier, the post-drilling techniques consist of three major methods.

A. Mud Logging Methods

Mud logging methods consist of the following process.

1. Measure Drilling parameters (ROP, WOB, RPM, flow rate).
2. Measure properties of drill cuttings from samples collected at the shale shaker.

3. Measure gas levels from well.
4. Produce a lithological column as well is drilled.
5. Help determine accurately the depth of casing seats.

B. Measurement while drilling (mwd) & logging while mwd/lwd

These tools provide a variety of downhole drilling and electric log parameters which are applicable to the detection of abnormal pore pressure while drilling. With the exception of WOB and torque, all the following parameters can be measured either by wireline methods after the well is drilled or while drilling using Logging-while drilling methods. Depending on the type of MWD/LWD tool selected for the well any or all of the following parameters may be available.

C. Direct Measurements of Pore Pressure

Repeat Formation Tester Data (RFT) Drill Stem Test Data (DST).

Limitations and Conclusions

Seismic interval velocities can be used to estimate pore pressure section from surface seismic data but accurate seismic velocities are required for reliable results and offset well data for comparison. Pre-drill pore pressure prediction approach requires integration of surface and borehole measurements to minimize drilling risks and reduce the cost of drilling.

Obviously, the RFT and DST pressure data are the most definitive and have the least uncertainty associated with them. Mud programme and casing seat selection can therefore be based on RFT and DST pore pressure values. While the RFT (Repeat Formation Tester) and DST (Drill stem Test) data provide definitive values of pore pressure for the well, these direct measurements are only possible in permeable formations and are obtained after the well is drilled. They are also not applicable to the surrounding, largely impermeable, shale sections where the majority of overpressure is developed.

Estimates and calculations of pore pressure from mud logging, wireline and drilling log data are restricted solely to shale sections. Establishing a normal compaction trendline (normal pore pressure trendline) is of great importance when calculating pore pressure from log derived shale properties. Of the various logs available, sonic log data is considered to be the most accurate, as it is largely unaffected by borehole size, formation temperature and pore water salinity.

References

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