PaperID **AU133**

Author **Debajit Saha , ONGC , India**

Co-Authors **K. K. Pattanaik, D. P. Singh**

Pore pressure calculation from well logs in a well in Wadu field and its implications

Abstract:

Knowledge of pore pressure of an area is of paramount importance as it forms the basis of well design for drilling. The difference between pore pressure and fracture pressure is the mud window and the drilling mud weight must always be kept within this range for safe and smooth drilling with minimum non-productive time. Pore pressure can be calculated from the wells already drilled within the area and can give vital leads for future wells. Eaton's (1975) resistivity method modified by Zhang (2011) has been used to determine pore pressure gradient from resistivity logs recorded in a well in Wadu field in Ahmedabad area. The normal compaction trendline was determined from Tarapur Shale formation. The pore pressure gradient shows fair correlation with the measured RFT pressure data and the mud weight used to control a minor kick observed in the well. The pore pressure gradient also depicts the difference in pressures in Younger and Older Cambay Shale formations. The Younger Cambay Shale formation was found to be overpressured and the pressure in Older Cambay Shale was found to significantly lower than that. This can possibly be attributed to the differential compaction of shales in Younger and Older Cambay Shale formations.

Introduction:

Pore pressure is one of the most important parameter which forms the basis of well design. Abnormal pore pressure, if not anticipated beforehand, can result in significant amount of non-productive time arising out of kick, blowout and severe well complication etc. during drilling of a well. Casing depths and drilling fluid parameters are planned according to the pore pressure profile of an area before drilling of a well.

Out of all the stresses acting on a wellbore, the knowledge of pore pressure and fracture pressure is very crucial. The drilling fluid (mud) pressure is normally kept greater than the pore pressure so that no fluid can enter the wellbore during the course of drilling. The entry of unwanted fluids (water, oil or gas) into the wellbore can cause kick and even lead to blowout with disastrous consequences. On the other hand, the pressure exerted by mud also needs to be kept below the fracture pressure (minimum horizontal stress). If the mud weight is increased above the fracture gradient during drilling, it will result in fracturing of formation which in turn will cause severe well complications (e.g., mud loss, stuck up etc.). Thus pressure exerted by mud needs to be always kept in the range between pore pressure and fracture pressure. This range is called mud window.

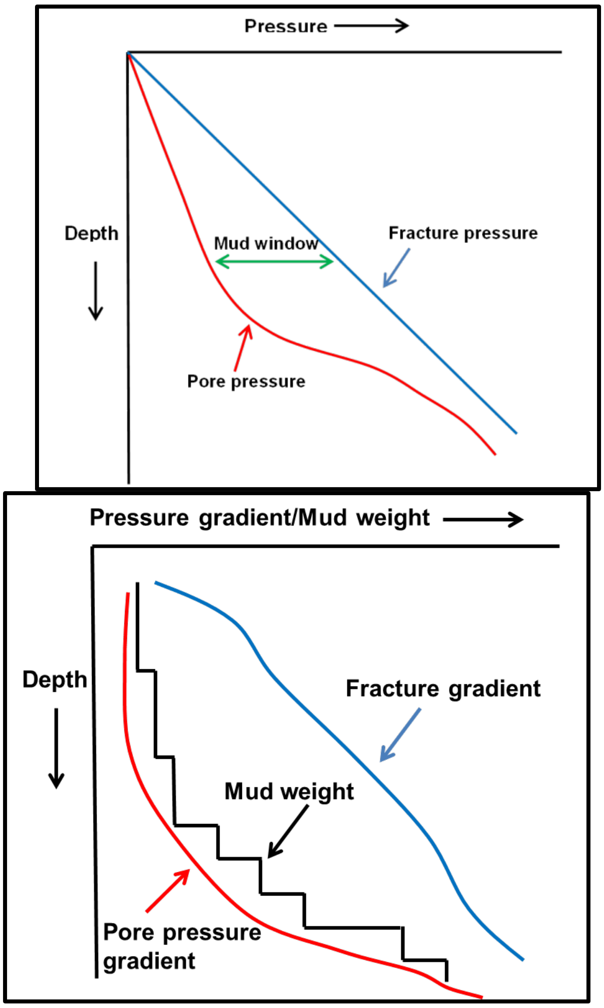
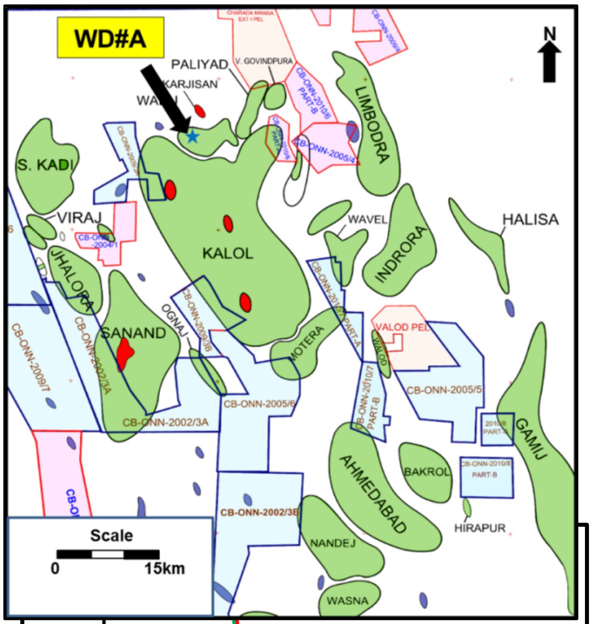


Fig.1. Pore pressure, fracture pressure and mud window

Pore pressure gradient is the change of pore pressure per unit depth. Pore pressure gradient is more convenient in well planning than pore pressure itself as it can be easily compared with mud weight that has to be maintained during the course of drilling.

Fig.2. Pore pressure gradient, fracture gradient and mud weight



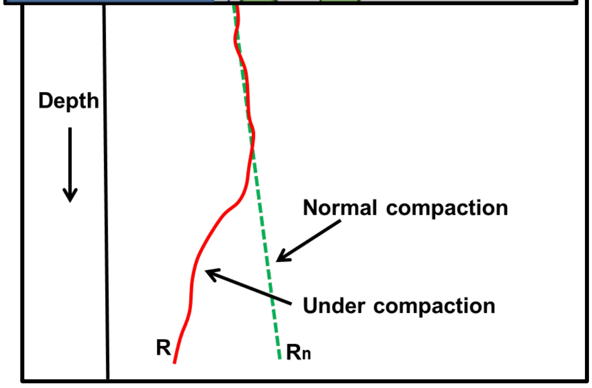


Fig.3. Resistivity and normal compaction trendline (After Zhang, 2011)

Methodology:

In young sedimentary basins where under-compaction is the prime reason behind overpressure in shales (, Eaton's resistivity method is widely used for determining pore pressure prediction from resistivity log. The original equation of Eaton (1975) can be presented as:

P_{pg} = OBG – (OBG - P_{ng}) $(R / R_n)^n$ …………(i)

P_{pg} = formation pore pressure gradient, OBG = overburden gradient, P_{ng} = hydrostatic gradient (normally 0.433 psi/ft or 0.1 ksc/m), R = resistivity of shale obtained from well log, R_n = resistivity of shale at the same depth on the normal compaction trendline of an area, n = Eaton's exponent and it is usually considered to be 1.2 in current geopressure community (Zhang, 2011).

R_n is again a function of burial depth. Considering this, Zhang (2011) proposed a modified Eaton's equation which can be presented as:

$$P_{pg} = OBG – (OBG – P_{ng}) (R / R_0e^{bz})^n \text{ …………….. (ii)}$$

R = resistivity of shale measured at depth Z from log, R_0 = shale resistivity in the mudline, Z = depth below mudline and b = slope of logarithmic resistivity normal compaction trendline.

Study area:

The well selected for present study is located in the Wadu field in the northern part of Ahmedabad block of Cambay Basin (Fig.4). The generalized stratigraphy along with the lithology of the area is given below (Table 1):

Fig.4. Field map of Ahmedabad with the location WD#A

Age	Formation	Lithology
Middle Miocene - Recent	Post kand	Alluvium and clay
Middle Miocene	Kand	Clay/claystone and sandstone
Lower Miocene	Babaguru	Sandstone with minor clay/claystone.
Upper Eocene-Oligocene	Tarapur Shale	Shale with minor siltstone
Middle – Upper Eocene	Kalol	Majority shale with intercalations of sandstone/siltstone and coal layers
Middle - Lower Eocene	Younger cambay shale	Majority shale with minor sandstone/siltstone layers
Lower Eocene	Older cambay shale	Majority shale with minor siltstone layers
Paleocene	Olpad	Claystone, trapwacke
Cretaceous	Deccan trap	Deccan trap basalt

Table 1. Generalized stratigraphy of Wadu field

Different pays within Kalol formation are the main producer in this area and wells are normally drilled upto Cambay Shale formation.

Our studied well WD#A was drilled vertically upto the depth of 2277m. The schematic well diagram is given below (Fig.5):

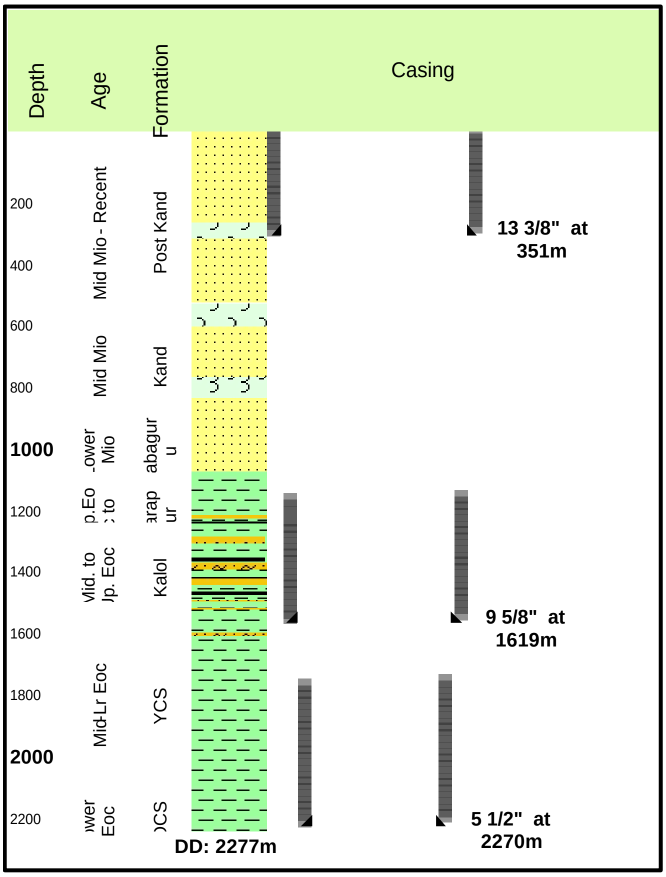


Fig.5. Schematic diagram of the well WD#A

Standard open hole logs were recorded in the well. Apart from the basic logs, RFT pressure tests were also carried out at different depth points. The RFT pressure data was included in our study to verify whether the derived pore pressure data matches with the values from RFT or not.

Derivation of normal compaction trend:

The stratigraphic formations encountered in the area above Tarapur formation are Kand, Post Kand and Babaguru. These formations consist of alluvium, clay and sandstone. On the other hand Tarapur formation consists of predominantly shale with minor siltstone layers towards bottom. Hence for derivation of normal compaction trend line (NCTL) in shale Tarapur formation was found to be ideal.

Resistivity values (from log) were plotted in logarithmic scale against depth and a normal compaction trend line was drawn (Fig. 6). Intersection point of the NCTL was considered to be ‘R0’ and the slope to be ‘b’. The values of these factors were found to be 0.8 and 0.00050891 respectively.

Calculation of pore pressure gradient:

OBG (overburden gradient) in equation (ii) was derived from the density log recorded in the well. The derived values of R0 and b were put into the equation (ii) and pore pressure gradients were derived and plotted (Fig.7). RFT pressure data recorded in the well were also plotted to verify the entire method in this case.

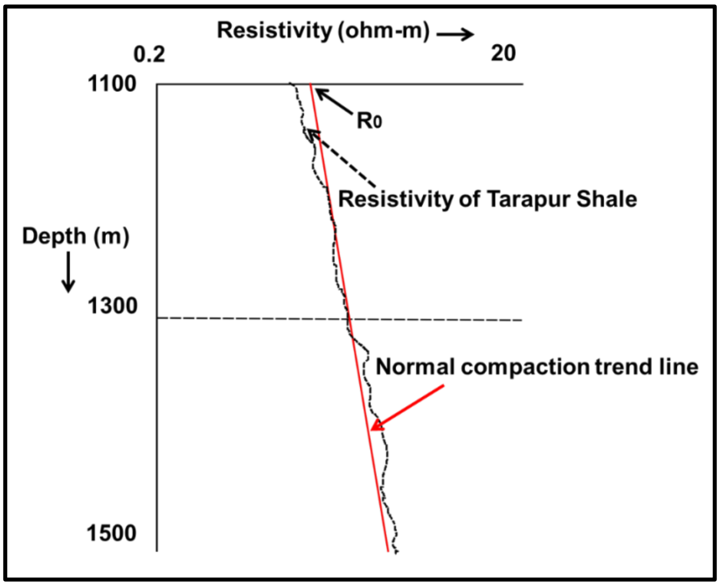


Fig. 6. Resistivity and normal compaction trend line in Tarapur Shale

Results and discussions:

The derived pore pressure gradient varies from one formation to another. Tarapur shale formation shows more than hydrostatic pore pressure gradient. Kalol formation has been found to be hydrostatic to slightly sub-hydrostatic. In Cambay Shale, distinct variation is observed between Younger and Older Cambay Shale. Younger Cambay Shale is over pressured whereas Older Cambay Shale shows much lower pressure gradient. The RFT data recorded in the well match with the derived trend.
During drilling the well, minor kick was observed at 1780m wherein 1.45 sp. gr. Mud weight was being used. The kick was controlled by increasing the mud weight to 1.54.

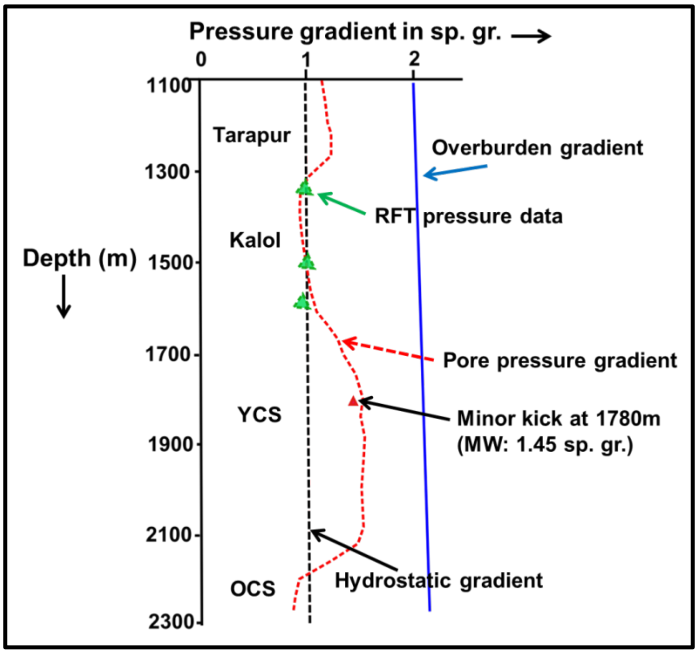


Fig. 7. Pore pressure gradient of the well WD#A

The study suggests that the mud weight (1.45 sp. gr.) was slightly lower than the pore pressure gradient which resulted in the kick.

The higher pore pressure in Younger Cambay Shale compared to Older Cambay Shale is probably due to under-compaction in Younger Cambay Shale. This type of compaction disequilibrium has been cited as the main reason behind overpressure in many young sedimentary basins across the world (Law and Spencer, 1998; Liu et al., 2018).

Conclusions:

Pore pressure gradient profile generated from resistivity values from open hole logs gives good understanding of the pore pressure in different formations in the well. Higher pore pressure in Younger Cambay Shale can probably be attributed to under-compaction which is in turn related to faster rate of burial during sedimentation and diagenesis. Large scale study of this kind will be able to give a better idea about the pore pressure profile of the entire field and the variations within it. The variation of pore pressure in the same formation in different parts of the field will enable us to compartmentalize the field which will be helpful in future well planning.

Acknowledgements:

The authors are indebted to ONGC management for providing infrastructure and permission to publish this paper. The authors wish to thank Shri S. D. Sarkar, DGM (Geology), ONGC for his valuable suggestions and comments. The authors also acknowledge the support and guidance rendered by their colleagues.

References:

Eaton, B. A. (1975). The equation for geopressure prediction from well logs. Society of Petroleum 748 Engineers of AIME, paper SPE 5544.

Law, B.E., and C.W. Spencer, (1998). Abnormal pressures in hydrocarbon environments, in Law, B.E., G.F. Ulmishek, and V.I. Slavin eds., Abnormal pressures in hydrocarbon environments: AAPG Memoir 70, p.1–11.

Liu, H., Jing, C., Jiang, Y., Song, G., Yu, Q. and Feng, Y. (2016), Characteristics and Genetic Mechanisms of Overpressure in the Depressions of Bohai Bay Basin, China. Acta Geologica Sinica - English Edition, 90: 2216-2228. doi:10.1111/1755-6724.13032

Zhang, Jon. (2011). Pore pressure prediction from well logs: Methods, modifications, and new approaches. Earth-science Reviews - EARTH-SCI REV. 108. 50-63. 10.1016/j.earscirev.2011.06.001.