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"Prediction of High Pressures in HP-HT well - A case study from KG Basin, East coast of India"

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Summary

Abnormal pressured rocks are typical of many sedimentary basins world wide. Prediction of over / high pressures in the sedimentary sequences in any sedimentary basin is indeed a challenging problem. In Krishna Godavari Basin, over / high pressures occur in the subsurface from 1500m downwards and in thick sections of fine-grained sediments. Over / high pressures in a formation is a concern during all phases of Oil/Gas field operations viz., drilling, logging, testing, stimulation, completion and reservoir evaluation.

This paper deals with the concept of over pressures, causes for generation and, prediction of these pressures during drilling. The ultimate aim of prediction of these pressures is to use optimum mud weights , to avoid drilling complications like well kicks, mud loss, stuck ups, fishing operations etc, for safe & cost effective drilling and finally to generate quality geo-scientific data.

In the present study, one deep, high temperature & high pressure exploratory well in onland part of Krishna Godavari Basin, which was under drilling, has been chosen for case study. The main mechanism responsible for most over/ high pressure conditions in the basin appears to be continued delta progradation with rapid rate of sedimentation. Several techniques available for forecasting the abnormal over/ high pressures in the subsurface are analyzed in this paper.

The dynamic drilling analyses have guided in designing the well programmes, including mud parameters and resulted in smooth and successful drilling of the Well up to the target depth of 4800m without much complications.

Introduction

The Krishna-Godavari basin (Figno.1) constitutes a typical passive margin basin and has a polycyclic (dual-rift province) evolution history. It comprises a wide array of sedimentary facies from Early Permian through Cenozoic with analogous outcrops in the northwestern part. To the Northeast and Southwest of this basin, along the East coast, lie the Mahanadi and Cauvery basins. Broad tectonic expression of the basin comprises linear horst-Graben system, growth fault/rollover and block tilting along synthetic fault over intra shelf regime followed by toe thrust, thus exhibiting a manifestation of typical passive margin.

An attempt has been made to study and predict abnormal pressures in Oil and Gas exploration in KG Basin. Two dominantly variable conditions that affect every petroleum reservoir is pressure and temperature, and each of them is a form of stored and available energy. Of the two reservoir conditions, Pressure probably has a wider effect than temperature. The fluids confined in the pores of the reservoir rock occur under a degree of pressure called reservoir pressure, or formation pressure. In much of geology of petroleum, we are dealing with lower temperature and pressures. But, in certain areas like K.G Onland, and with increasing depths that drilling is capable of attaining, we are reaching into the realms of high pressures.

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Prediction of High Pressures in HP-HT well

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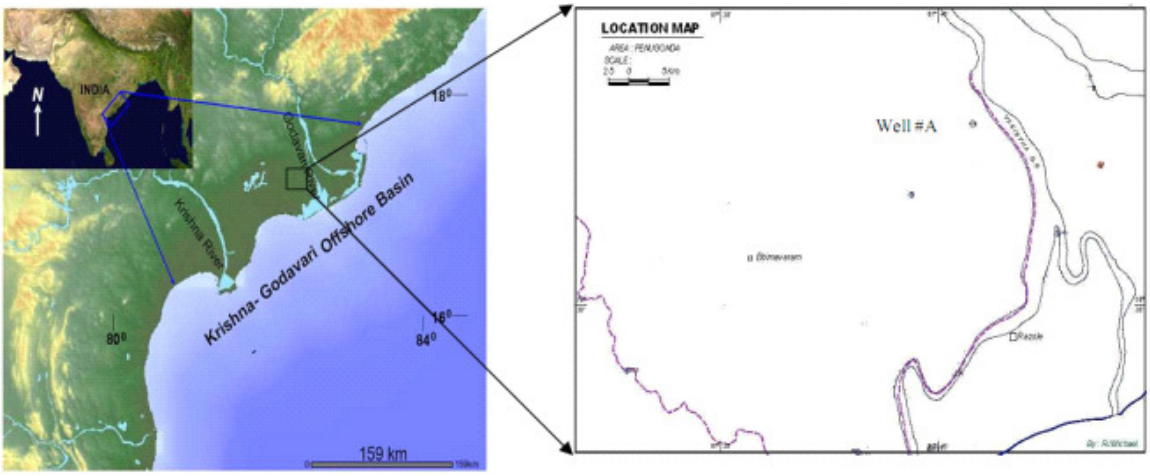
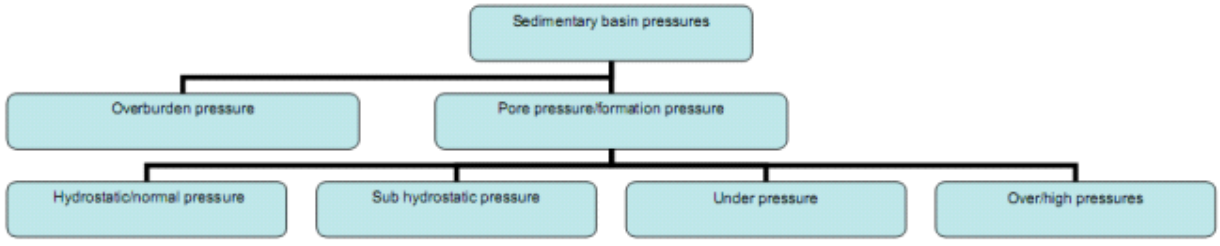


Figure-1 Location map of Krishna Godavari Basin

Excess reservoir pressures are difficult to measure because they are frequently encountered unexpectedly. When sufficient heavy drilling mud is used to protect against high pressure and blowout, there is a danger of lost circulation when high pressure mud entered low pressure or thief zones. Lost circulation of drilling mud, in fact is a possible indication of low pressure formation. When such a formation is located within a sequence of high pressure formations, it is often of significance in the location of potential producing reservoir.

Concepts and Method of study

Pressure is the force per unit area applied on a surface in a direction perpendicular to that surface. In sedimentary basins different kinds of pressures are encountered, which are broadly divided into two main heads.



Methods adopted for predicting over pressures:

The following methods have been adopted dynamically during drilling of the well to predict Over Pressures/under compaction of sediments

1. 'd' Exponent
2. Shale density studies
3. Shale factor
4. Flow line temperature
5. Sonic Travel time analysis

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1. 'd' Exponent:

'd' exponent is defined as the drillability of formation and is mainly studied in the shales/ impermeable rocks lying above the over pressure reservoir rocks. dcs exponent studies decrease in'd' exponent trend. "d" Exponent which facilitates plotting of a normalized penetration rate Vs depth.

$$Dcs = \frac{Log(R)/18.29N}{Log(W)/14.9B} \times Weq/ECD$$

2. Shale density:

High pressures are associated with under compacted sediments. Shale density is useful in locating the high pressure horizons that are likely to be met during the course of drilling. In such cases of high pressures environment, the shales show lower density.

3. Shale factor:

Shale factor analysis is also utilized for over pressure detection. An increase in the montmorillonite clays will mean lighter density shale which could mean that it could be interpreted as under compacted shale. Shale factor gradually decreases with depth in normally pressured regimes and, shows an increase in an over pressured zone.

4. Flow line temperature:

Flow line temperature normally shows an increasing trend with depth following the geothermal gradient. In over pressure regimes, an increase in FLT trend, beyond normal gradient is observed.

5. Sonic Travel time analysis:

Sonic velocity gradually increases with depth, due to compaction of sediments and with more overburden. In a normal compaction trend a gradual increase in sonic velocities is observed with depth. In under compacted sediments there is a drop in sonic velocity and increase in travel time.

Interpretation and results:

1. 'd'exponent:

In this well,'d' exponent studies have been carried out from 100meters depth onwards. (Figure- 2) 'd' exponent plot is enclosed which is plotted against depth along with formation pressure(PF), mud weight used during drilling(Mwt) and Formation fracture gradient.

After plotting the'd' exponent continuously, trend lines are plotted for identifying the changes in trends of pressure regimes. The present plot shows a normal trend up to 2500metres. Which is reflected by the Formation pressure also, from 2500 to 3100m there is a change in trend to the lower side indicating the initiation of overpressure. The zone may be transitional zone between the normal pressure regimes above and over pressure regimes below. Below 3100 meters the 'd' exponent curve clearly shows a marked changing in trend to the lower side indicating overpressure regime. The same is reflected in the formation pressure, being higher than the hydrostatic pressure.

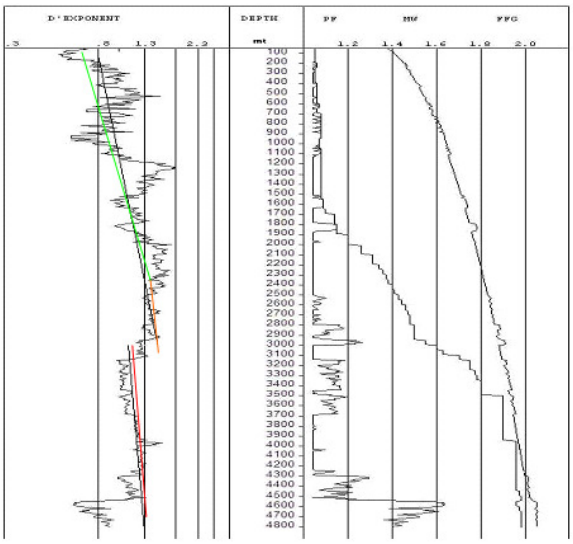

Figure-2. 'd' Exponent plot of Well#A

2. Shale Density:

Shale density studies are carried out from 500metes depth onwards. (Figure-3). Which is plotted against depth? .After

plotting the shale density continuously, trend lines are plotted for identifying the changes in compaction with depth. The present plot shows a normal trend up to 1900 meters increase in shale density from 2.00 to 2.3 gm/cc. From 1900m-2900m there is a change in trend to the lower side (decreasing up to 2.0 gm/cc) indicating the initiation of overpressure. The zone may be transitional zone, between the normal pressure regimes above and overpressures below. Below 3100 meters the shale density plot shows a decrease in trend indicating the overpressure regimes. The same is reflected in the shale factor with a slight increase in shale factor trend and also in'd' exponent as a decreasing trend.

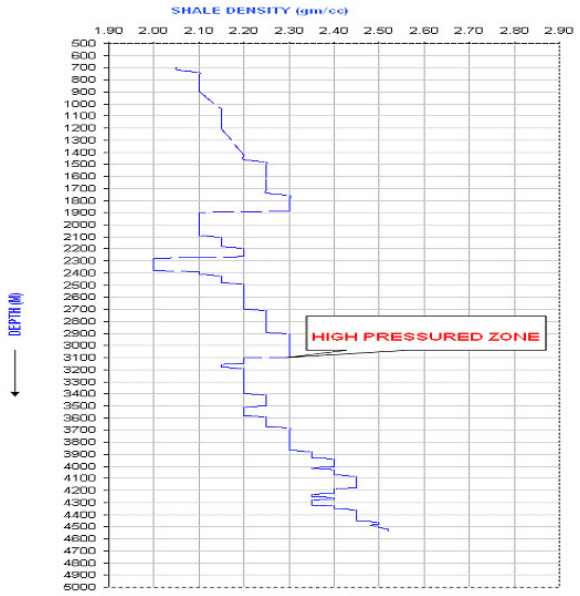

Figure-3. Shale density Plot of Well #A

3. Shale Factor:

Shale factor studies were carried out with shale samples from 700meters onwards. (Figure- 4) The Shale factor is measured as Cation Exchange Capacity, which shows a gradual decreasing trend, in normally compacted sediments. In the present well, the studies indicate that the CEC (Cation Exchange Capacity) values decrease from 34.00 to 29.5 with depth.. From 3100m to 3700m and below 4200 mts. there is an increase in shale factor trend, which indicates under compacted sediments. These sections coincide with the anamolies observed in the Shale Density and d'exponent trends indicating under compacted / over pressured sediments.

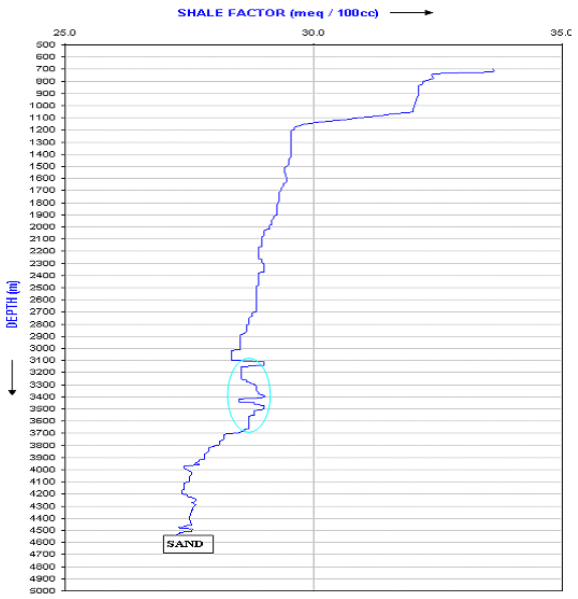

Figure-4. Shale Factor Plot of Well#A

4. Flow line Temperature:

IN the study well, Flow line temperature is plotted against depth.(Figure- 5) The plot shows a gradual increase in flow line temperature with depth. At around 1700mts, a sharp rise in trend of FLT is observed, followed by gradual increasing trend with depth. Several intervals are observed, where, a sharp rise in FLT is observed followed by a drop. These cycles, where sharp rise in FLT is observed fall in the under compacted zone, as supported by'd' exponent, shale density, Shale factor etc plots. The drop in FLT in these cycles may due to changes in lithology from Shale to Sand, as temperature drops are lithology and saturation dependent.

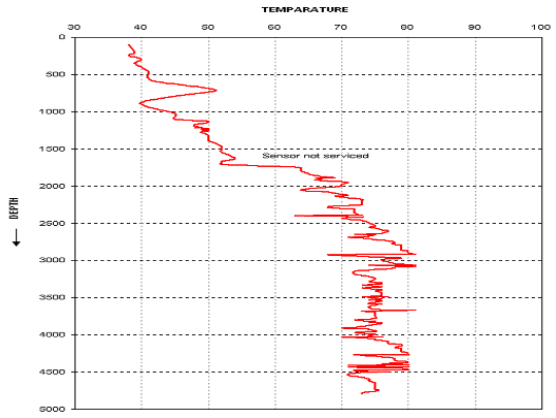

Figure-5.Flow Line Temperature plot of Well#A

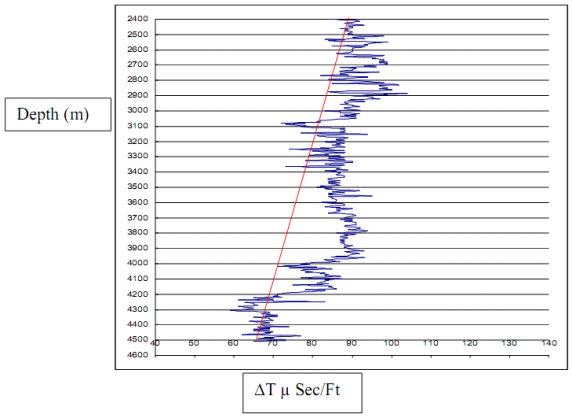

Figure-6. Sonic Travel Time Analysis Plot of Well #A

5. Sonic Travel Time Studies:

In the well under study, sonic velocities have been compiled and plotted against depth.(Figure- 6) This plot shows a normal compaction trend, with depth, with decreasing travel times (suggesting increased velocities). Anomalies have been observed in the intervals 3350-4000mtr and 4050-4200mtr, where a decrease in sonic velocities and increase in travel time is observed.

Studies of 'd' exponent, Shale Density, Shale Factor have indicated the initiation of overpressures from around 3100mtr. The sonic data analysis shows anomalies from around 3100 mtr. This falls in the over pressure regime, but the top of over pressure regime is not well defined. As factors like bad hole conditions, presence of gas, affect the sonic log, a clear cut coincidence with other factors may not be observed. Any how, these anomalies below 3500mtr, which indicate under compaction /Over pressure regimes fall in same zones as those indicated by other anamolies like d'exponent, Shale Density, Shale Factor and Flow Line Temperature

Conclusions

Prediction of Over/high pressures in the sedimentary sequences of Krishna-Godavari basin is indeed a challenging problem. For a reliable prediction, one deep exploratory well categorized as high temperature& high pressure well in the west Godavari sub basin of onland part of KG Basin have been identified for drilling analysis .The study leads to the following conclusions.

- Abnormal over/high pressures occur in the subsurface of KG Basin from 1500m downwards and in thick sections of finegrained sediments.
- The main mechanism responsible for most over/high pressure conditions in the basin appears to be continued delta progradation with rapid rate of sedimentation associated with tectonics, Compaction, Diagenesis etc.
- High pressure regimes are encountered in Tertiary and Mesozoic systems.
- Several gas pools are trapped in isolated reservoirs, truly sealed after burial. These sequences have shown over/high pressure, probably due to lithification and diagenesis, combined with rapid rate of sedimentation.
- High pressures are normally associated with well kicks and blow outs which are a big drilling hazard for men and material.
- In the dynamic drilling phase, various studies like'd' exponent, Shale density, Shale factor, Flow Line Temperature, Sonic travel time analysis,etc have been carried out to predict the over/high pressure regimes.

- 'd'exponent studies in well#A indicate that the normal pressure regime is observed up to a depth of 2500m, from 2500 to 3100m appears to be a transitional regime and an over pressure regime was noticed from 3100m and below.
- Shale density studies clearly indicate a marginal fall with shale density values in the interval 3100-3600m which coincides with a negative 'd' exponent trend. These indicate under compacted formations.
- Shale factor (C.E.C) studies indicate an increase in CEC values in the interval 3100-3700m which coincides with negative trend of'd' exponent and reduced values of shale density, there by indicating overpressure regimes.
- Flow line temperature anomalies (i.e increase) have been observed at certain depth intervals .e around 3100mm ˜ 3500, ˜3700m and around 4300 to 4400m. These anomalies are coinciding with the other parameters like 'd'exponent, Shale density, Shale factor, flow line temperature etc.
- The Dynamic drilling analysis have guided in designing the well programmes including mud parameters and resulted in smooth and successful drilling of the well#A up to the target depth of 4800m without much complications.

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