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Pore Pressure Prediction, analysis of High-Pressure Formation using well data and other available geo-scientific data: A case study of Bantumilli graben in Krishna Godavari Basin, India

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Abstract:

The Krishna-Godavari Basin is characterized by its wide spread hydrocarbon habitat and multiple petroleum systems including unconventional biogenic system. A number of oil and gas fields have been found both in land and in the offshore and out of which a number of wells have encountered high pressure and high temperature. High pressure and high temperature (HP-HT) pose unforeseen problems in successful drilling and completion of a well. Prior knowledge of pressure and temperature regime and availability of continuous pore pressure and temperature data will be immensely useful in successful drilling, acquiring of OH log data and completion of a well. The prediction of pore pressure, overburden gradient and fracture gradient through G&G data and demarcation of HP-HT zone in the interested areas of KG Basin is prerequisite for further exploration in deeper plays. Hence data of pore pressure, fracture and overburden gradient of nearby wells have been taken into consideration and got validated through LOT and MDT data for pore pressure prediction, identification and analysis of High-Pressure Formation before drilling of the interested well which will help in designing proper mud weight and casing policy.

Introduction:

Safe and economical drilling of new wells for exploration of hydrocarbons in complex and unpredictable geological formations may prove to be difficult at times. Knowledge of in-situ formation pressures or sudden high-pressure zones add benefits to deal with well complications. Therefore, it is vital to the planning of drilling wells to have an estimate of the expected pressure regime to be encountered in the subsurface. Accurate knowledge of formation pressure helps in designing proper mud weight and casing policy which may be helpful in prevention of kicks, formation damage, circulation loss, borehole collapse and even blowout. Therefore, the accurate pore pressure prediction is a significant factor in designing, drilling operations, well servicing and abandonment. There are many causes for overpressures in sedimentary Basins such as disequilibrium compaction, tectonic compression, hydrocarbon generation, aqua thermal expansion, mineral dehydration, mineral transformation, vertical fluid movement, and hydrocarbon buoyancy. Many sedimentary Basins throughout the world exhibit above hydrostatic fluid pressure, KG Basin is also one of them. High pressure and high temperature (HP-HT) pose unforeseen problems in successful drilling and completion of a well. Prior knowledge of pressure and temperature regime, availability of continuous pore pressure and temperature data will be immensely useful in successful drilling, acquiring of OH log data and completion of a well. A significant oil discovery in a syn-rift reservoir was made in the onshore block in Bantumilli Graben, but the wells encountered in syn-rift generally show high pressure and high temperature and the reservoir is also tight. The main objective of this paper is to predict the pore pressure, fracture pressure and temperature gradients of the exploratory location **"D"** in Bantumilli graben using nearby well data for successful prediction of pressure and temperatures. Pore pressure and fracture gradients give a safe window for drilling fluid used in a well. Mud weight that is used in a well during drilling should be between Pore Pressure Gradient (PPG) and Fracture Gradient (FG) to avoid drilling complications. Demarcation of HP/HT areas at the top of Raghavapuram Shale, HG-HR and other Syn-rift sequences have done for successful drilling and completion of the well D.

Geological Setting of the study area:

Krishna-Godavari Basin is a pericratonic rift Basin in the central part of East coast of India. The characteristic feature of this Basin is the presence of en-echelon system of horsts and grabens filled with thick pile of Permian to Recent sediments (Figure.1). Commercial accumulation of hydrocarbon is

seen in sediments of all ages from Gondwana to as young as Pliocene Godavari clay. Bantumilli South prospect is situated in the grabenal part, south of Bantumilli High and is considerably big structure. The interested well D is falling in Godavari Onland PML block of KG Basin on Bantumilli South prospect for exploration of Nandigama arenaceous unit (Figure-2). Earlier three wells drilled i.e. A, B and C on the same prospect for exploration of Nandigama Arenaceous unit were prematurely terminated, inconclusively tested, and permanently abandoned due to technical complications. The recent oil discovery from Syn-rift sediments in Bantumili area in Bantumili Graben and promising lead (gaseous presence on logs) in Kottalanka area has provided significant impetus to the exploration of hydrocarbon within Syn-rift sequence not only in Bantumili Graben, but also entire Basin.

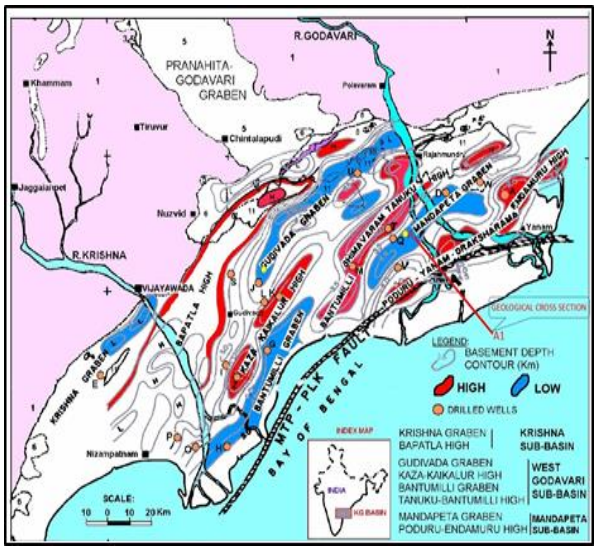

Figure-1: Basin Fill Map of Krishna Godavari Onland Basin

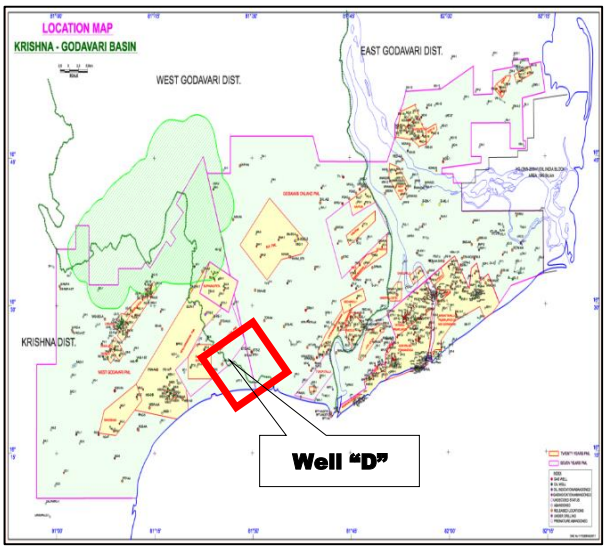

Fig. 2: Location of well-D in Bantumilli graben in KG-PG Basin

Methodology:

The data pertaining to formation pressure are integrated for the study which includes mud weight during drilling, casing details, MDT record, production testing record, LOT/PIT record, 'D'-exponent data, shale density, shale factor data, bottom hole temperature details and lithological information collected for the well bore. Log data recorded from the wells are used to extract lithological, density, porosity, velocity information of the formations. Well-wise pore pressure gradient, fracture gradient, over burden gradient, minimum and maximum stress magnitudes were estimated and from the pore pressure curve PP maxima against transition pressure zone and high-pressure zone were estimated. The depth corresponding to these values were noted and it provides the depth of maximum pressure in the well. Temperature corresponding to the same depth is also noted. In all wells, the maximum pressure recorded in the well and the corresponding depth and temperature were collected. As per industry standards 10000 psi and 300° F are considered as the criteria for selection of high pressure and high temperature wells. Hence, the depth at which the wells encountered 10000 psi are noted along with corresponding temperature. Pore pressure determination requires some essential steps, based on certain assumptions. The essential assumption is that the pore pressure of sand layer is equal to that of the adjacent shale. It should also be remembered that shale is chosen as the reliable compaction trend indicator because shale behaves more uniformly than sand. The shale is first required to be discriminated out of the sand.

Discussions:

Pore Pressure Analysis from Well Data: Pore pressure analysis for the interesting well "D" has been done by using offset well correlation which requires Mud Wt. data, Casing data, LOT/ PIT data, Formation Pressure data and temp data of the nearby wells and log method. But use of Log data for pore pressure prediction gives more accuracy as it represents the true subsurface picture of nearby

wells. Well log composites showing pressure gradient data along with log curves have been generated for all the key wells with the adoption of above-mentioned methodology. Since OBG is over gradient pressure which combines both pressure in the matrix as well as in pores. Therefore, it will be always maximum, which is also shown in the mentioned plates. Fracture gradient is just lagging behind the OBG, which indicating the behaviour of geo-mechanical strength of particular formation (Figure.3). The details of the wells taken for the study are given below:

Well A:

The well "A" is an exploratory well drilled down to a depth of 4223m with an objective to explore Syn-rift sequence of Nandigama unit. As per present study the pore pressure curve shows normal pressure from surface to 2880m, transitional regime from 2880m to 3406m, again a small normal pressure regime from 3406m to 4070m and an abnormal high-pressure regime from 4050m to 4223m. The maximum transitional Pore Pressure Gradient (sg) of 1.36 sg occurs at depth 3164m and corresponding fracture and over burden gradient values against same depth are 1.94 sg and 2.25 sg respectively. The maximum high PPG is 1.80 at 4060m and corresponding F.G and OBG are 2.14 sg and 2.3 sg respectively (Figure-4).

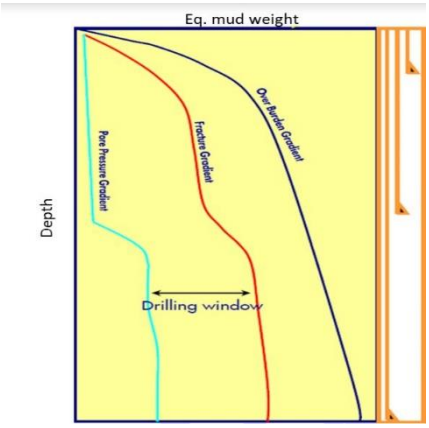

Fig. 3: Plot showing relationship between pore pressure gradient, Fracture gradient and over burden gradient.

D- exponent was calculated from surface to 4223m (TVD). The plot shows 4 pressure regimes. Normal pressure from surface to 3600m, transitional pressure regime from 3600m to 4050m, again a small normal pressure regime from 4050m to 4150m and an abnormal high pressure from 4150m to 4223m. Shale density data shows gradual increase of density values with depth down to 4070m, indicating normal pressure regime from surface to 3200m, transitional pressure regime from 3200m to 4070m again normal pressure regime from 4070m to 4223m (Figure.5).

Temperature Gradient:

Temperatures recorded during different phases of logging were used to estimate temperature gradient. Mean surface temperature is considered to be 30°C.

Interval (m)	Temperature gradient (°C/100m)
Surface to 2066	3.05
2066 to 3400	1.77
3400 to 4100	8.57
Overall	3.58

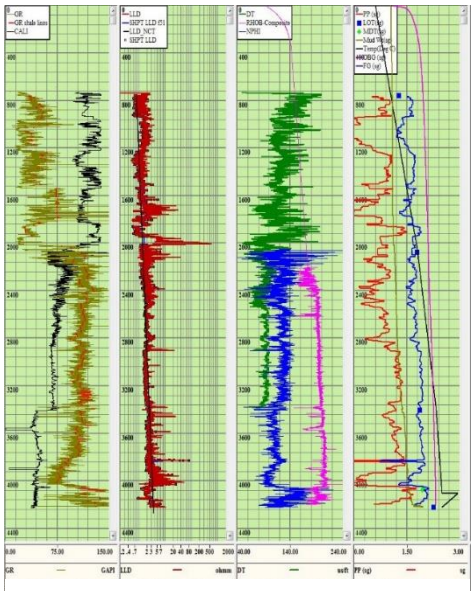

Fig. 4: Pore pressure, Fracture and Overburden and temperature gradients plot of well-A

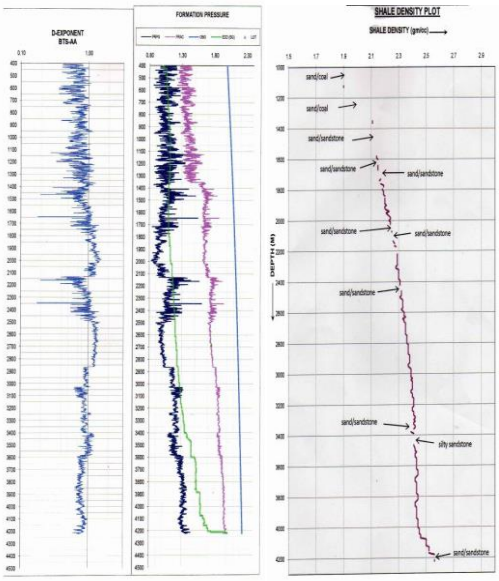

Fig. 5: D-exponent and shale density plots of Well-A

Well-B:

The well “B” is an exploratory well drilled down to a depth of 4359m with an objective to explore Syn-rift sequence of Nandigama unit. As per present study the pore pressure curve shows normal pressure from surface to 3660m, transitional regime from 3660m to 4080m and high-pressure regime from 4080m to 4547m. The maximum transitional Pore Pressure Gradient (sg) of 1.6 sg occurs at depth 3870m and corresponding fracture and over burden gradient values against same depth are 2.15 sg and 2.38 sg respectively. The maximum high PPG is 1.78 at 4090m and corresponding F.G and OBG are 2.16 sg and 2.39 sg respectively (Figure-6).

The D-exponent studies indicate normal pressure regime from surface to 3930m, transition to high pressure from 3930 to 4150m and high-pressure regime below 4150m. Shale density data shows normal pressure regime from 650m to 3100m, transitional pressure regime from 3100m to 3930m and abnormal high-pressure regime from 3930m to 4150m (Figure-7).

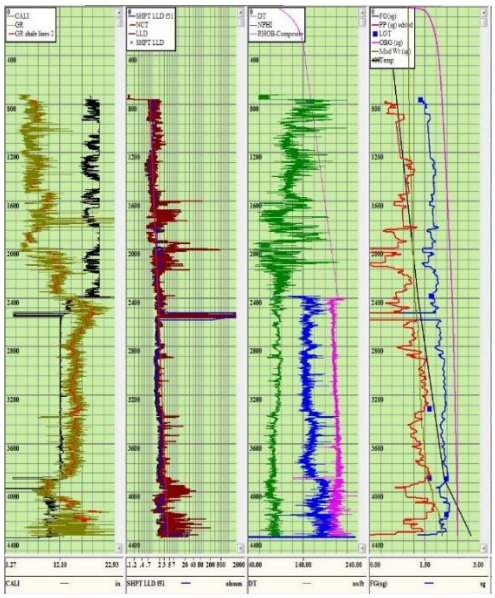

Fig. 6: Pore pressure, Fracture and Overburden and temperature gradients plot plot of well-B

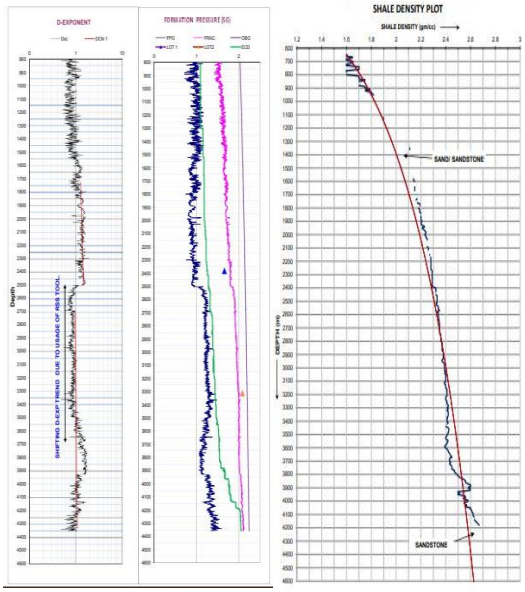

Fig. 7: D-exponent and shale density plots of well-B

Temperature Gradient:

Surface temperature was considered as 30°C. Maximum estimated bottom hole temperature at 4373m is 185.1Deg C. The overall temperature gradient is 3.55°C /100m. From 3900 m to 4359 m indicates, very high temperature gradient having transition to abnormal temperature and pressure regime.

Interval (m)	Temperature gradient (°C/100m)
Surface to 2388	2.4
2388 to 3895	3.22
3895 to 4359	10.5
Overall	3.55

Well-C:

The well-C is an exploratory “B” category well drilled down to a depth of 4600m with an objective to explore Syn-rift sequence of Nandigama unit. Fig. As per present study the pore pressure curve shows

normal pressure from surface to 2980m, high-pressure regime from 2980m to 3440 m and from 3760 to 4600m.The maximum high PPG is 1.836 sg at 4060m and corresponding F.G and OBG are 2.07 sg and 2.18 sg respectively (Figure 8).

D-exponent was calculated from 540m to 4600m. The plot suggests normal pressure up to 2615m. The D-exponent plot shows some shift from normal trend line in the intervals from 3100m to 3500m and from 4150m to 4350m, indicating higher pressure regime. Shale density data shows gradual increase of density with depth up to 3370m. The under compaction was noticed in the interval from 3370m to 3420m and 3480m to 3530m indicating some abnormal pressure regime and the same was observed during drilling with gas kick at 3452m (Figure 9).

Temperature Gradient:

Temperatures recorded during different phases of logging were used to estimate temperature gradient. Mean surface temperature is considered to be 30°C.

Interval (m)	Temperature gradient (°C/100m)
Surface to 2066	3.5
2066 to 3400	1.77
3400 to 4100	8.57
Overall	3.58

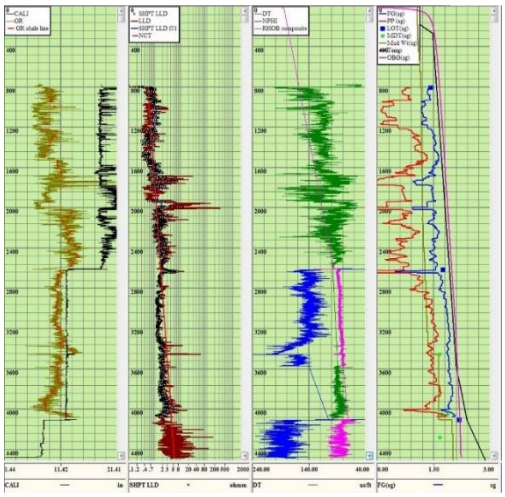

Fig. 8: Pore pressure, Fracture and Overburden and temperature gradients plot of well-C

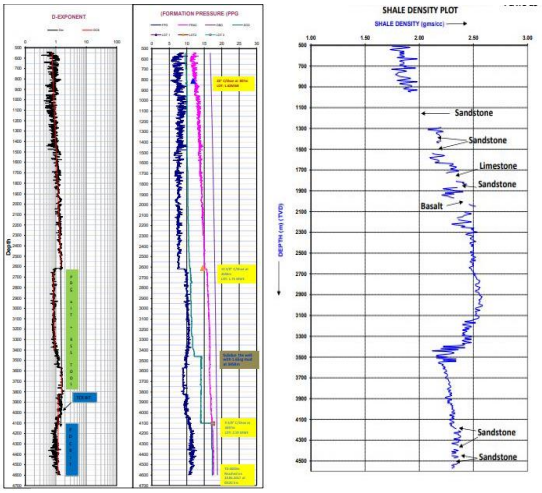

Fig. 9: D-exponent and shale density plots of well-C

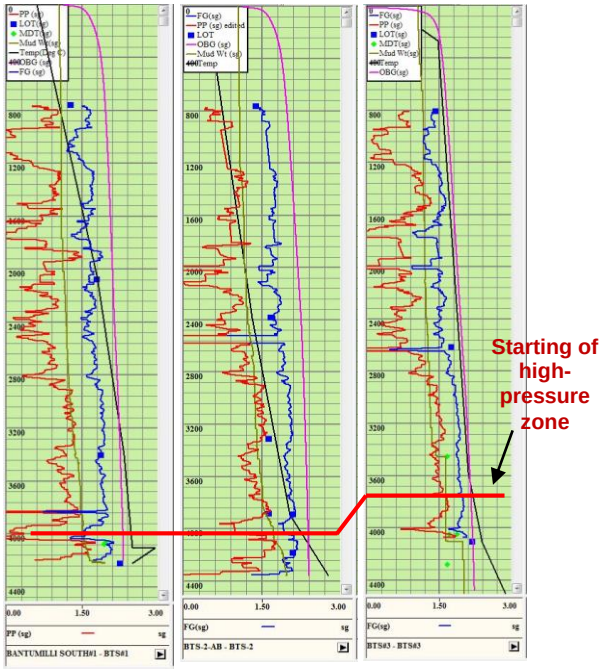

Fig. 10: Correlation of high-pressure zone of reference wells

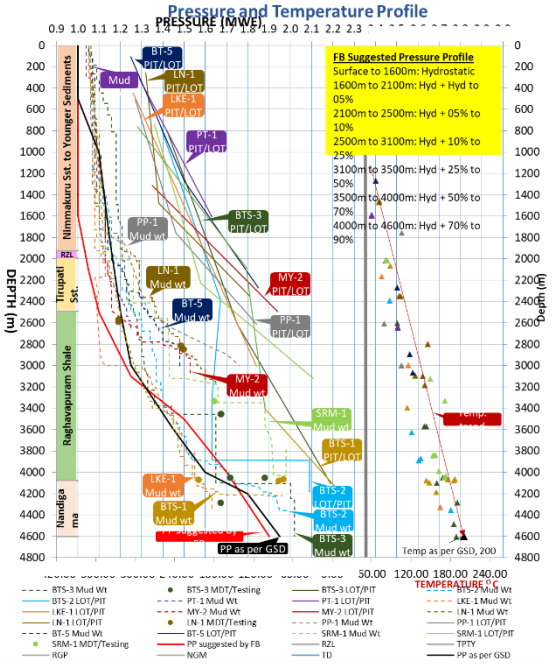

Fig. 11: predicted Pore pressure gradient and Temperature gradient of the well "D" from Offset Wells

Pore Pressure gradient, Fracture gradient, Over Burden gradient and Temp gradient for the three wells have been plotted for pore pressure and high-pressure zone prediction of the new interested location "D". From the correction studies of the nearby wells, it is observed that high pressure zones start nearly around 4000m and HP zones are encountered in Raghavapuram formation in all the three wells (Figure-10). High pressure zone top varies within ±200m from Syn-rift top and not correlateable through seismic. The patchy correlation follows the synrift trend. The synrift sedimentation and deposition of Lower Raghavapuram shale plays an important role for high pore pressure zone development. The Exploratory location "D" in Bantumilli field which is to be drilled more than 4500m is also expected to encounter high pressure zone in Raghavapuram Formation and predicted to have a thickness of around 1600m from 2490 - 4080m (as per GSD data). A preliminary pore pressure prediction has also been done using offset wells data which predicts the maximum pressure at 4600m to be 12428 psi (Figure-11). The pore pressure analysis of the location "D" gives an advantage for preparation of HP-HT conditions for drilling the well. Several challenges are encountered during the HP-HT well operations and these can be mitigated easily with prior knowledge of the pressure and temperature conditions.

Further continuous data of pore pressure, fracture and overburden gradient can be calculated by considering the data of already drilled wells and generation regional isobar and isotherm maps can be done for better understanding of the Bantumilli Graben. The same can be correlated throughout the basin for bringing out pressure variation across the basin. An overall idea about the pressure conditions of the graben and the whole basin can be beneficial in better planning and designing of wells to be drilled in future and for smooth operations.

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- Regional study for high pressure and high temperature regime and its origin with special reference to syn-rift sequence of KG Basin using well data and other available geo-scientific data (A project led by Abul Basar, Dy. S.G., Wells and supervised by Deepak Kapoor, DGM, Wells)

- WCRs of all the selected wells