

Formation Temperature and Pressure Analysis and Implication in Tectonic setup-KG basin

well **balances** the formation pressures at the respective depths. (Higher mud weights might cause mud losses and lower mud weights would result in well activity. In case of these two complications encountered in wells, the controlled mud weights are considered as balanced). Of course, there are some cases observed that the formation pressure (the RFT pressures in MWE are 1.59 & 2.09 whereas the mud weights corresponding to the depths are 1.48 & 1.85) is more than the mud weights maintained while drilling and vice versa.

- Testing and MDT data in MWE is preferred to mud weight used wherever the data is available and balanced mud weights considered if data is not available. For temperature too, testing and MDT data is preferred and read the highest values if more than one log run is carried out.
- It is difficult to have formation/stratigraphy wise Pressure-Temperature data, as the depth of occurrence of all stratigraphic units are highly variable. For instance, the BSMT depth in the basin varies from 500m on Bapatla high to more 6000m in Offshore as these two parameters increases with HC occurrence and sediment thickness.

Observations/Inferences

Formation Temperature: It would be meaningful to compare temperature gradients measured from surface to Basement or from surface to a common depth level. However for statistical information - the overall temperature gradient in the basin range from a minimum of 2.65^oC/100m to a maximum of 4.29^oC/100m onland. Maximum recorded temperature onland is 223.88^oC in well on flank of Poduru-Yanam High at a depth of 5422m and offshore 178.89^oC in well (NE part of Basin) at a depth of 3951m.

At 2500m level (Figure 2) the formation temperatures ranges from a minimum of 32^oC in offshore KD area to a maximum of 138^oC in Ravva area, whereas at 3500m depth (Figure 3), the temperature range from 59^oC in offshore in KD area to a maximum of 174^oC in Amalapuram area. Relatively a small number of data points (wells) are available wherein factual data is available for 4500m depth. Other controls are the

extrapolated data points in the wells which were drilled down to depths between 4000m-4500m.

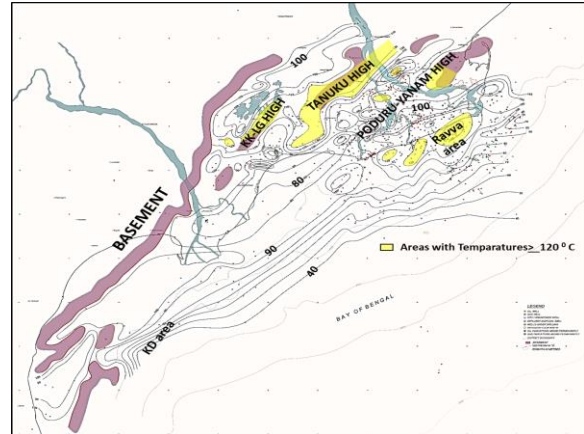


Figure 2: Formation Temperature map at 2500m Depth

Minimum temperature recorded at 4500m level (Figure 4) is in offshore ultra deep well (28^oC, water depth 2840m) and Maximum 208^oC in onland well on flankal part of KK-LG high (gradient 3.87^oC/100m).

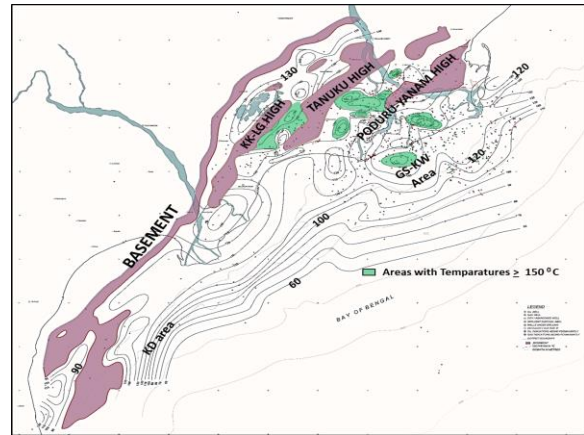


Figure 3: Formation Temperature map at 3500m Depth

The temperatures more than 120, 150 and 190^oC were highlighted on 2500m, 3500m & 4500m maps respectively. Wells drilled on Basement highs and areas close to flanks of basement highs showed relatively high temperatures at shallower levels as the causative/conductive source radiating the geothermal energy is shallower. The increasing trend in temperatures is observed with sediment thickness. At all three depth levels, it is observed that the isotherms show increasing trend towards East and North East part of the Basin compared to South and Southwest,

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this is due to increasing water depth and reducing sedimentary column thickness in South and SW. Higher geothermal gradients in NE part could also partly be due to the fact that the basin has its slope towards SE and SW which means that the sediment thickness increases in these two directions. Southerly decrease in temperature is also due to increasing water depth and reducing sedimentary column thickness.

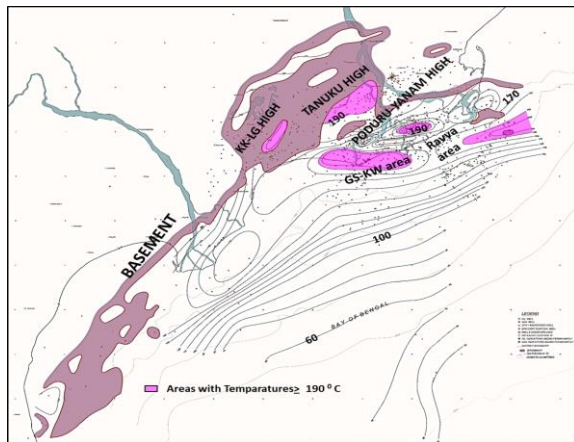


Figure 4: Formation Temperature map at 4500m Depth

Formation Pressure: Overall formation pressures/used mud weights in the basin range from a minimum of 1.1 MWE (a well on KK-LG High at a DD of 3138m) to a maximum of 2.24 MWE (South of MTP-PLK fault, at a DD of 3902m) onland and from a minimum of 1.12MWE at a DD of 2915m (ultradeep water well WD: 2840 m) to a maximum of 2.11MWE (NE part of the Basin at a DD of 4155m) offshore. Maximum recorded formation pressures onland is 2.18 MWE in South of MTP-PLK fault at a depth of 3485.5m and offshore 2.08MWE in a well (NE part of the basin) at a depth of 3966.5m.

From the maps (Figures: 5-7) it is inferred that minimum pressures are observed towards basin margin and deep water areas. SW part of the basin both onland and offshore possess lower formation pressures compared to its NE part. The Mud weights more than 1.5, 1.7 and 2.0 MWE were colored on 2500m, 3500m & 4500m maps respectively.

In few cases the used mud weights appear to be influenced by the psychological/intuitional element

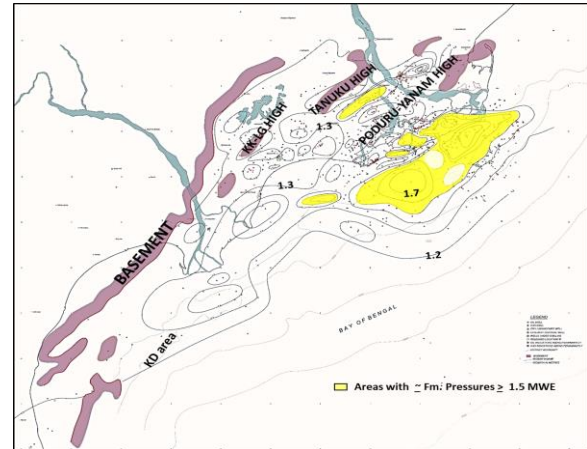


Figure 5: ≈ Formation Pressure map at 2500m Depth

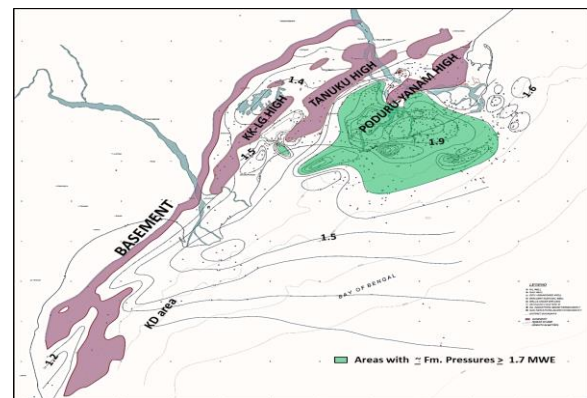


Figure 6: ≈Formation Pressure map at 3500m Depth

of the geoscientist engaged in well prognosis. Higher mud weights are used from shallower depths in case of deep wells positioned in deeper parts of grabens and lower mud weights in shallow wells positioned on basement highs. This factor, in the absence of actual pressure data, poses the problem of giving a distorted picture when mapped. Shallower levels are more prone to be complicated by this problem.

The HC generation process and depth of occurrence also plays a significant role in pressure development. In the grabenal parts of the basin, high pressures are observed at deeper depths as the sediment thickness increases. The effects of hydrocarbon generation, basal heat flow and sediment compaction on overpressure development in evolving sedimentary

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basins have been studied by Jennifer Hansom and Ming-Kuo Lee (2005). Oil generation can cause excess pore pressure (c. 425 atm) up to c. 40% of that generated by compaction only (c. 300 atm). Oil and CH₄ gas generation together yield the maximum excess pressure (c. 750 atm) up to about 150% of that generated by compaction only.

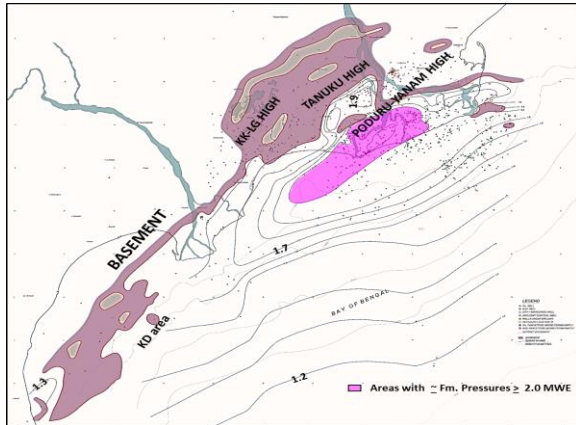


Figure 7: ~Formation Pressure map at 4500m Depth

So in this area, besides other normal causes, the HC generation factor also could have contributed for the development of high pressures.

Temp-Press Relationship with tectonic trends: The maximas of temperature and pressure areas majorly lying between the two prominent tectonic trends viz., Chintalapudi Cross trend and Yanam Cross trend (Figure 8 & 9). However it is observed that high temperature areas are extending towards Western part of the Chintalapudi Cross trend i.e., on KK-LG horst (as BSMT is shallow) and Bantumilli Graben. High Pressure zones also extending towards West of Chintalapudi Cross trend in Bantumilli & Malleswaram areas as the sediment thickness is more here. Further the Tanuku High appears to be the Northern limit for both temperature and pressure and the area close to the present-day Shelf edge forms the Southern limit for the temperature maxima. For Pressures the Southern limit extends upto 1000m isobath.

Temperature and Pressure - The Lithostratigraphic perspective: Temperature and Pressure profiles in strike and dip directions of the basin have been prepared depicting the distribution of

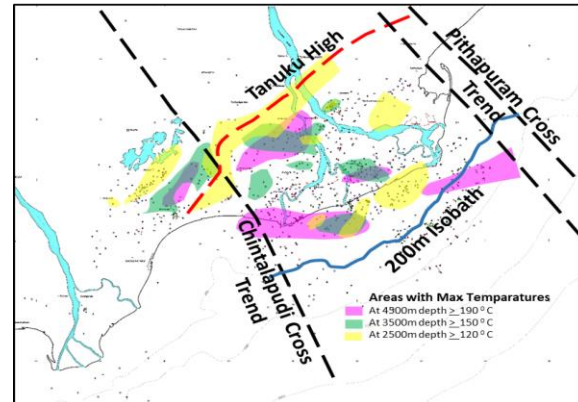


Figure 8: Map showing maximum Temperature areas at three Depth levels.

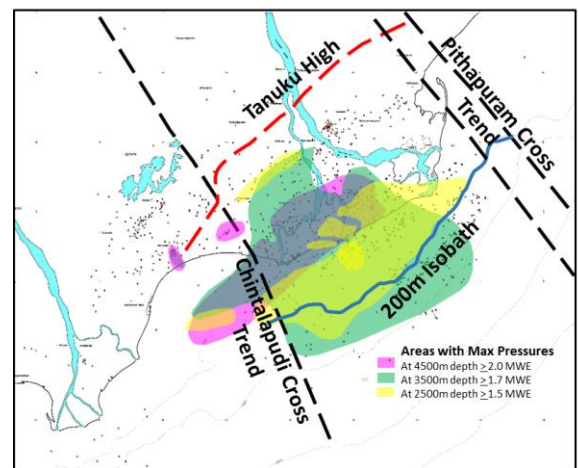


Figure 9: Map showing maximum ~Pressure areas at three Depth levels

isotherms and isobars vis-à-vis the stratigraphy (Figures 10-11). The temperature and pressure behavior with respect to lithostratigraphy is in general accordance with the basin's configuration (both structural and stratigraphic).

The electro log correlation along NW-SE, from MDP Graben to South of MTP-PLK fault, infers that even within the stratigraphic unit, both temp and pressure are varying as observed in Fig. 10. It is inferred that the temperature and pressures are cutting across the stratigraphic boundaries even within the same field. The MTP-PLK fault divides the tertiary basin into two tectono-stratigraphic regimes enabling the basin to have its depocenter (for tertiary section) to its south. Figure 12 depicts the broader stratigraphic

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corridor at 2500m depth with pressure contours overlay.

North of the MTP-PLK fault: From surface to the base of Tirupati sandstone the formation pressure is mostly within hydrostatic regime since the entire sedimentary section within this range (Tirupati Sst of Upper Cretaceous, Nimmakuru Sst and Narsapur clayst of Eocene and younger) is dominantly arenaceous.

The underlying Cretaceous shale section, Lower Rift and Older sequences show hydrostatic to transitional pressures exception being to the HC bearing zones where they range from hydrostatic/transitional to

higher.

South of MTP-PLK fault-

The area just to the south of the fault forms the distal part of Tirupati delta with the sandstone shale alternations and has hydrostatic pressures. Further south in the prodeltaic and deeper environs of Tirupati delta forms Chintalapalli shale having high to very high pressures. Razole formation of Lower Palaeocene showed high pressures. Intertrappean Sandstone within basalt flows tested in in this area showed pressures of 1.81MWE and 1.84MWE at 3620m and 3685m respectively.

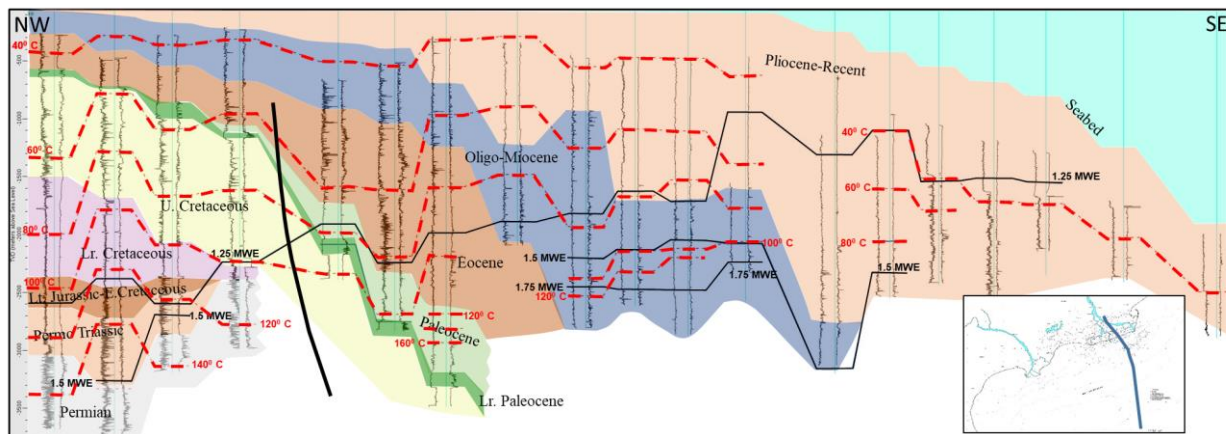


Figure 10: Temperature-Pressure profile in dip direction from NW-SE depicting the variation of the isotherms and isobars along different stratigraphic units

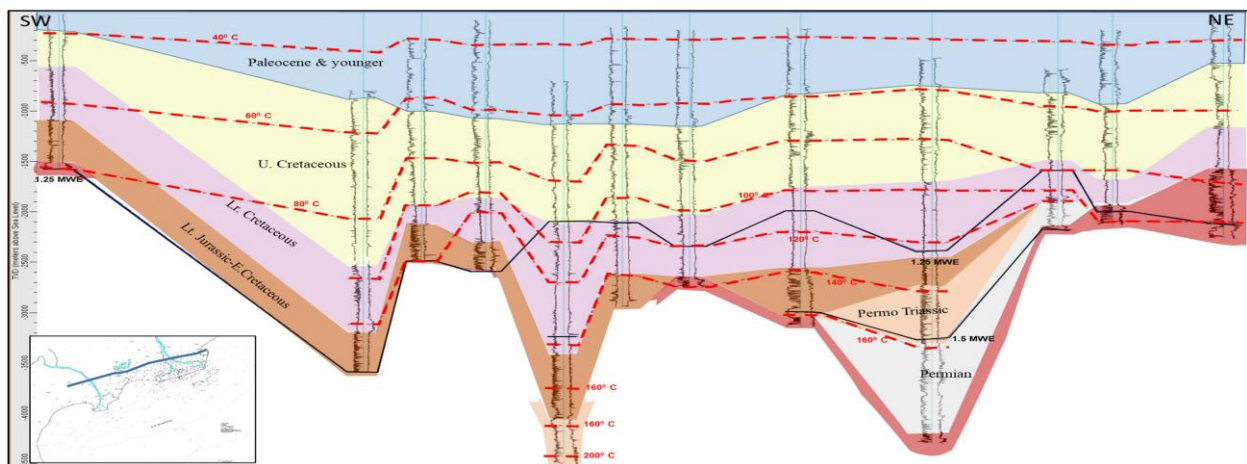


Figure 11: Temperature – Pressure profile in strike direction from SW-NE depicting the variation of the isotherms and isobars along different stratigraphic unit

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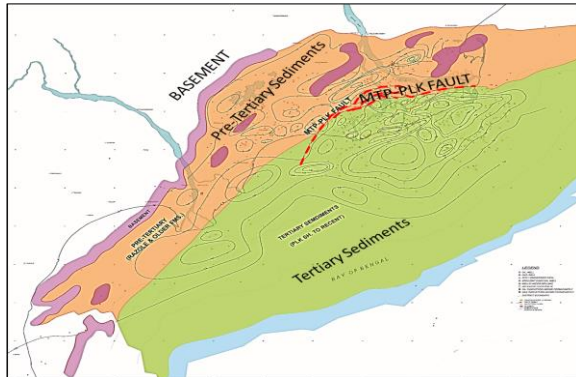


Figure 12: Formation Pressure Map at 2500m depth with broader stratigraphic corridors

Towards South of MTP-PLK fault, basalt thickness drastically varies (400m to 0m just within a short distance of 500m). This suggests fissure geometry, to these flows. The specific conductivity of heat of basalt is much higher as compared to other metamorphic and sedimentary rocks.

Also these igneous flows are sandwiched between two thick shales, Chintalapalli below and Palakollu above. It is observed, that the temp gradients increase as one approach Razole formation.

Palakollu shale of Paleocene which is dominantly argillaceous showed transitional to high pressure regime.

Pasarlapudi Sst being overlain by BMP Limestone (which is mud-loss prone) and younger arenaceous lithostratigraphic units exhibited hydrostatic to transitional pressure regimes.

Bhimanapalli Limestone of Middle Eocene age which is mud-loss prone (esp in Amalapuram-Bhimanapalli block) displays mostly hydrostatic to sub hydrostatic pressure regimes.

Matsyapuri Sst and overlying younger formations (U.Eocene to Recent section), being arenaceous in nature, display hydrostatic pressures.

Further basin ward, Vadaparru shale which is the time equivalent of Pasarlapudi Sst, BMP Lst and MTP Sst, showed transitional to high pressures.

Ravva Fm of Miocene recorded pressures ranging from near hydrostatic/transitional to high pressures. Godavari Clay of Pliocene in deep water showed transitional to high pressure.

Conclusions

- The Pressure and Temperature data of 530 key wells (340 wells onland and 190 wells offshore) have been considered for the study.

- Formation Temperature and \approx Formation Pressure maps of the basin were prepared at 2500m, 3500m and 4500m to demonstrate the variation of the parameters spatially and it was observed that these two parameter maxima are found to be confined to the NE part of the basin.
- These areas of maximum Temperature and \approx Formation Pressure mostly lying between the two prominent tectonic trends viz., Chintalapudi crosstrend and Yanam cross trend. Further the Tanuku High appears to be the Northern limit and the area close to the present day Shelf edge forms the Southern limit.
- Temperature and Pressure profiles in strike and dip directions of the basin have been prepared depicting the distribution of isotherms and isobars vis-à-vis the stratigraphy.
- From lithostratigraphic point of view, the distribution of the pressures has been discussed formation wise.

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- WCRs of all the key wells

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