IATMI22-192

Non-Linear Formation Temperature Profile in Mahakam Fields

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Abstract. Formation temperature data is commonly calculated by linear interpolation data anchored by bottom hole temperature (normally from LWD tool). LWD temperature is affected by wellbore dynamic such as mud circulation. Surface temperature which used in interpolation is usually over simplified by using fixed value for all field. The method of linear interpolation itself is also not always proper, because formation temperature is not always linear.

The surface temperature is varied by location, land and river has lower temperature than sea surface. The formation temperature measurement which likely not affected by wellbore dynamic are coming from stationary measurement such as wireline pressure test and fluid analysis (PT/FA) and drill stem test (DST). Formation temperature profile of Mahakam field is non-linear; the formula can be derived by using polynomial regression.

It seems that the non-linearity of temperature profile in Mahakam is mainly caused by lithology (Net to Gross ratio) rather than porosity (and fluid). Sands are having a very high thermal conductivity value. The effect of overpressure is look like less to temperature which probably due to well consolidated rocks close to and along overpressure interval.

This paper details the non-linear temperature profile in Mahakam fields, East Kalimantan, and further provides a technique to derive proper formation temperature profile formula which can be applied in other areas outside Mahakam.

Keyword(s): Formation Temperature

1 Background and Objective

Formation temperature data is commonly calculated by linear interpolation data anchored by bottom hole temperature (normally from LWD tool). LWD temperature is affected by wellbore dynamic such as mud circulation which make the tool read lower temperature than true formation temperature. Surface temperature which used in interpolation is usually over simplified by using fixed value for all field. In fact, surface temperature is varied by location. The method of linear interpolation itself is also not always proper, because formation temperature is not always linear. But there is a difficulty to generate proper non-linear temperature formula of each Mahakam fields.

The objective of this study is to have proper formation temperature profile formula of each field in Mahakam area.

2 Methodology

Methodology of this formation temperature study is by performing surface temperature evaluation in Mahakam, temperature data collection, and formation temperature formula regression.

2.1 Surface Temperature

Surface temperature of Mahakam delta is in the range of 22 – 31 degC (71.6 – 87.8 degF) based on reference study. The temperature of Makassar strait sea is in the range of 26 – 31 degC (seatemperature.org). Meanwhile, temperature of Balikpapan city is in the range of 22 – 30 degC (weather-and-climate.com). The temperature of land and river is lower than temperature of sea surface. It is normal because river is transporting water from higher land which has lower temperature.

2.2 Formation Temperature Data Collection

There are some sources of formation temperature data such as well logging, wireline pressure test and fluid analysis (PT/FA) and drill stem test (DST). Nowadays, well logging is commonly acquired while drilling (LWD). LWD temperature is affected by wellbore dynamic such as mud circulation which make the tool read lower temperature than true formation temperature. The formation temperature measurement which likely not affected by wellbore dynamic are coming from stationary measurement such as wireline pressure test and fluid analysis (PT/FA) and drill stem test (DST). Temperature from well log is usually lower than temperature from PT/FA (Figure 1). Temperature from PT/FA is similar with temperature from DST.

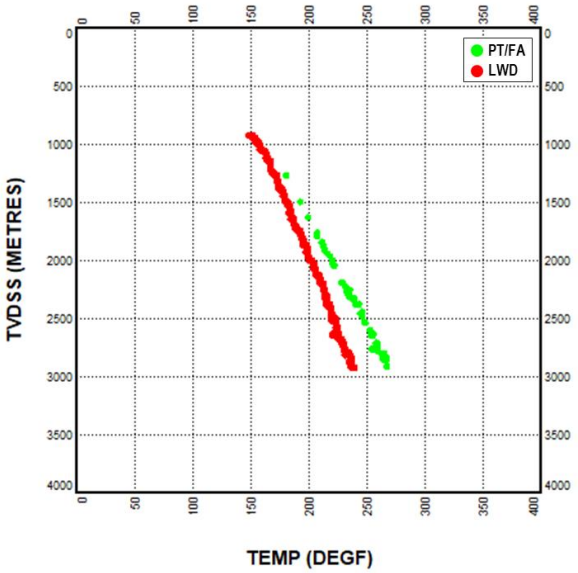


Figure 1. Comparison temperature from PT/FA and LWD in a well of Handil field.

Temperature data from PT/FA and DST is collected and stored in petrophysical software database. The temperature data of each Mahakam field is plotted versus depth (Figure 2). It shows that the temperature from PT/FA is in line with temperature from DST.

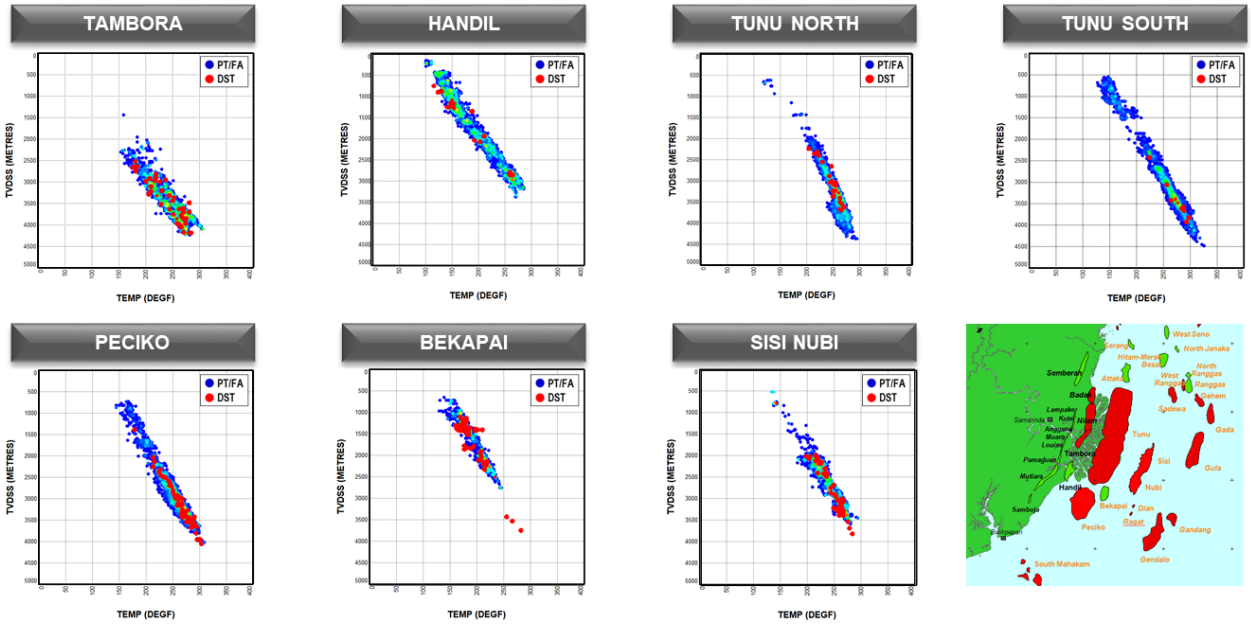


Figure 2. Temperature data of each Mahakam fields.

2.3 Formation Temperature Formula Regression

Formation temperature data of PT/FA and DST from hundreds wells in Mahakam fields shows non-linear temperature profile. Each field in Mahakam has unique formation temperature profile. Formation temperature formula is derived by using polynomial regression. The example of polynomial regression of Handil field is in Figure 3. The best formula which fit with temperature data over the whole interval is 5th order regression.

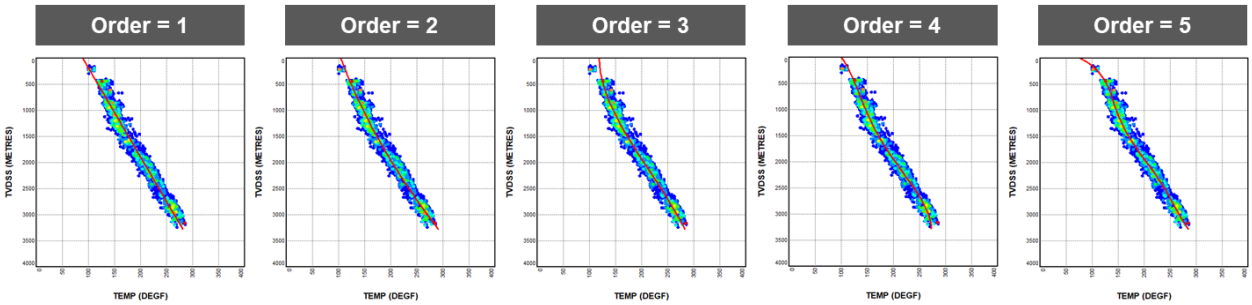


Figure 3. Polynomial regression order sensitivity of Handil field temperature data.

Polynomial regression of each Mahakam field is in Figure 4. The best formula which has best fit with temperature data of all field is 5th order regression.

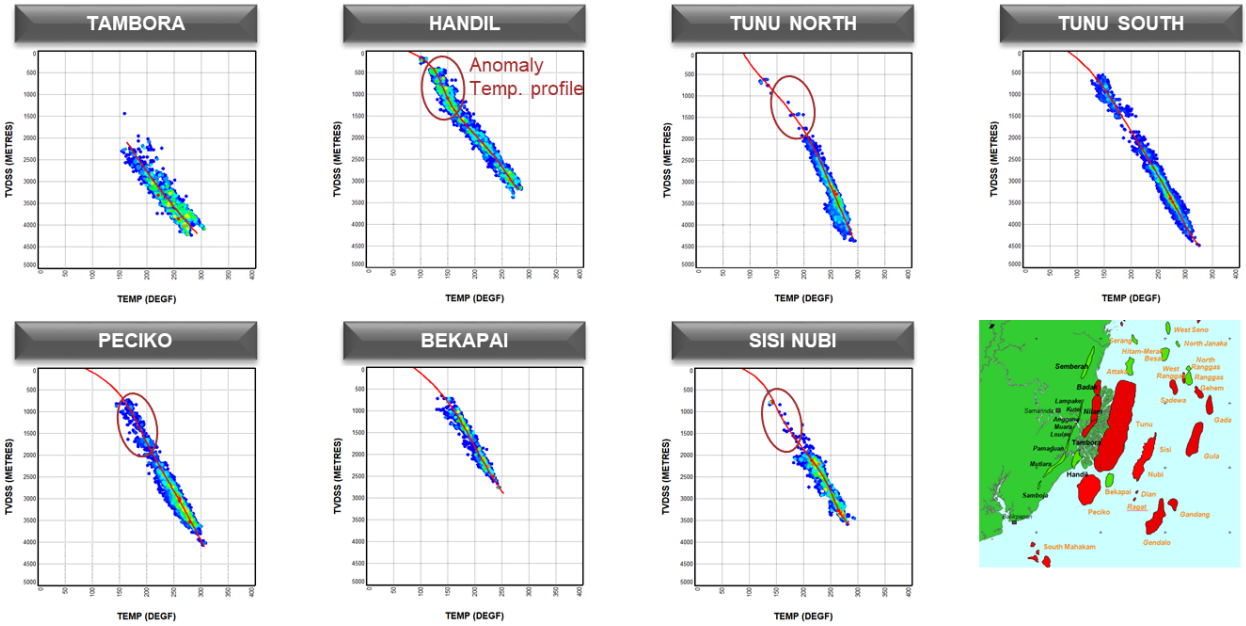


Figure 4. Polynomial regression of all Mahakam fields.

3 Results and Discussion

Formation temperature data of PT/FA and DST from hundreds wells in Mahakam fields shows non-linear temperature profile. Each field in Mahakam has unique formation temperature profile.

3.1 The Cause of Formation Temperature Profile Non Linearity

Temperature profile of Handil field (Figure 5) has significant bump at interval above 1200 m SS. Interval 400 – 1200 m SS has lower geothermal gradient than interval below 1200 m SS. Evaluation of possible cause of that geothermal gradient difference has been performed. The factors which evaluated are pore pressure, water salinity, fluid type, lithology, and porosity.

Pore pressure and water salinity are considered not affecting the anomaly of temperature profile. However, the fluid type seems to have an impact as on this interval is dominated by Water (or Waterise). Pore pressure of interval 400 – 1200 m SS is hydrostatic, similar with interval 1200 – 3000 m SS. Water salinity variation is not in line with temperature profile. Fluid type of interval 400 – 1200 m SS is similar with interval below 1200 m SS which is mixed of gas, oil, and water (Figure 5).

Lithology and porosity are also having an impact on affecting temperature profile anomaly (non-linearity). Lithology is represented by Net to Gross (NTG) ratio which is the ratio of sandstone reservoir and non-

reservoir (shale and coal). Interval 400 – 1200 m SS has NTG ratio of ~40% which is significantly higher than NTG of interval below 1200 m SS (~20%) (Figure 6).

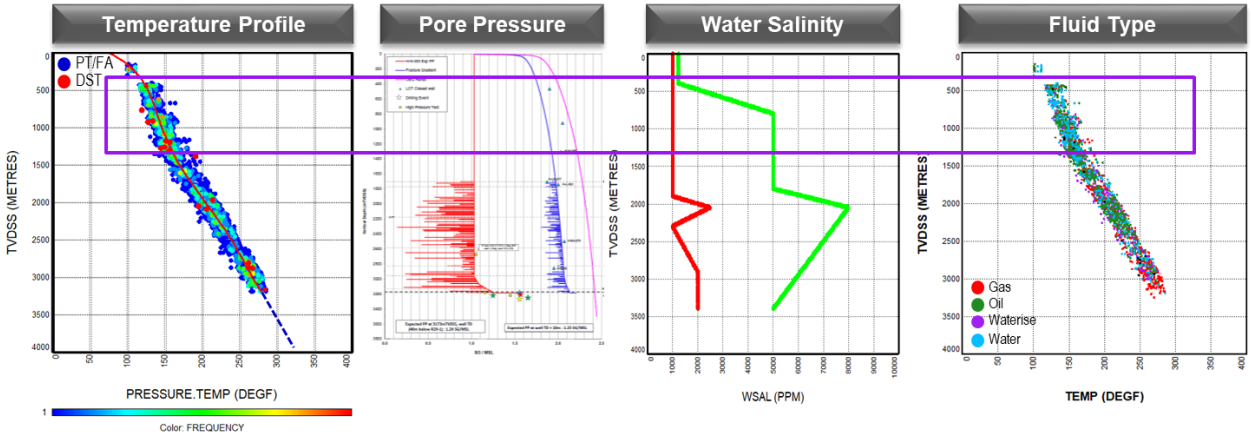


Figure 5. Temperature profile versus pore pressure, water salinity and fluid type in Handil field.

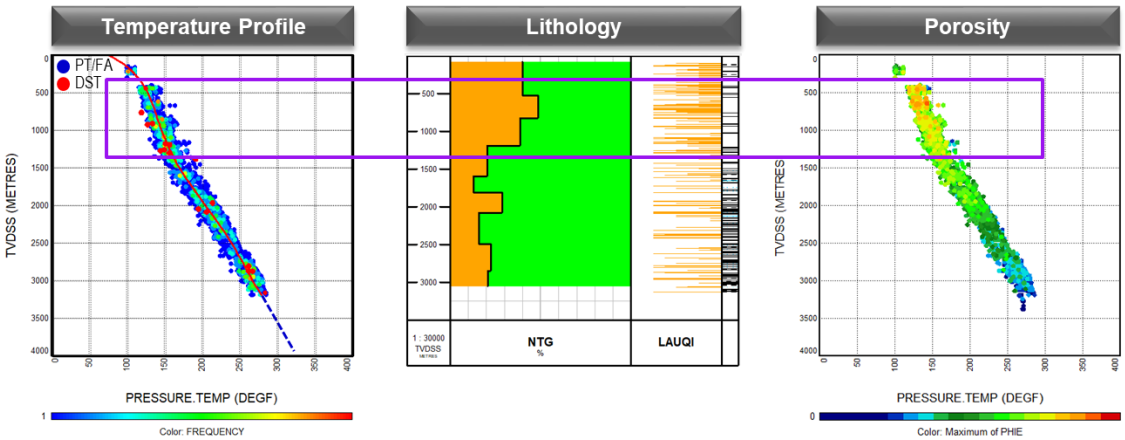
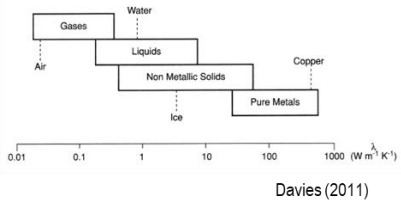


Figure 6. Temperature profile versus lithology and porosity in Handil field.

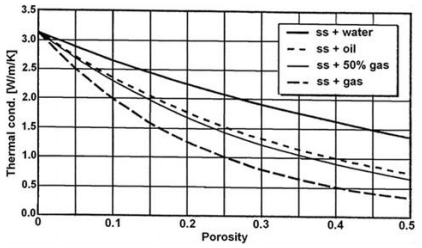
Lithology or NTG ratio difference is affecting temperature profile because sandstone has significantly higher thermal conductivity than shale and coal. The thermal conductivity of a material is a measure of its ability to a particular material conduct heat. The higher the thermal conductivity value, the better the medium can distribute the heat, hence consistent / same temperature in the medium.

Component	Thermal conductivity ($W\ m^{-1}\ K^{-1}$)
Sand	7.0
Shale	1.9
Water	0.6
Hydrate	0.45
Coal	0.3
Dolomite	7.0

Henninges (2005)



Davies (2011)



Poelchau et al. (1997)

Figure 7. Thermal conductivity of sedimentary rocks, fluids, and porosity (Henninges, 2005; Davies, 2011; Poelchau *et al.*, 1997).

It seems that the non-linear temperature profile in Mahakam is mainly caused by lithology (Net to Gross ratio) rather than porosity (and fluid). Sands are having a very high Thermal Conductivity value (7.0), and the abundant of Net to Gross (NTG) in the interval is quite massive. Having dominant water fluid in the interval is giving less impact on decreasing thermal conductivity value.

3.2 Temperature Profile Comparison of Mahakam Fields

Comparison of formation temperature profile shows different variation in each depth. This temperature profile variation is because of variation in lithology and structure. By sedimentology, the net to gross (NTG) ratio is decrease to distal (East), but by structure the East is deeper than the West (Figure 8).

Tambora field has significantly lower temperature profile than other field, it is probably because Tambora location is the fartest from sea, very close to Mahakam delta apex, and possibly there is any radiator effect of water charging from Mahakam river.

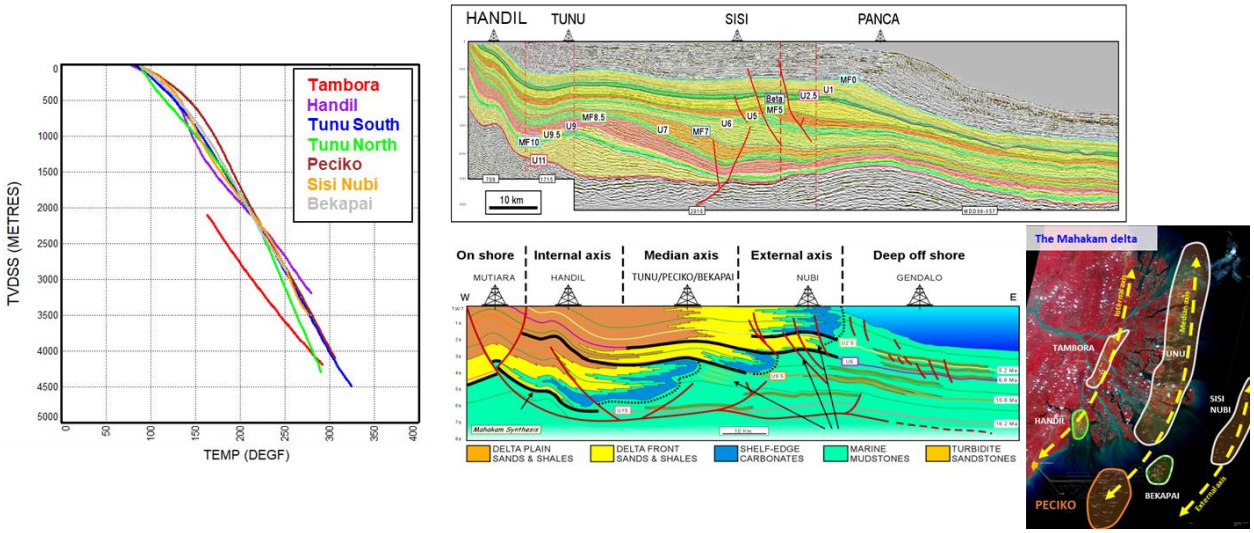


Figure 8. Formation temperature profile comparison of each Mahakam fields.

3.3 Temperature at Overpressure Interval

The effect of overpressure is look like less to temperature. Some slight change of temperature gradient at the top of overpressure seems to develop in Sisi-Nubi (Figure 9). This is probably due to well consolidated rocks close to and along overpressure interval, hence the lithology contrast between sands and shale is low.

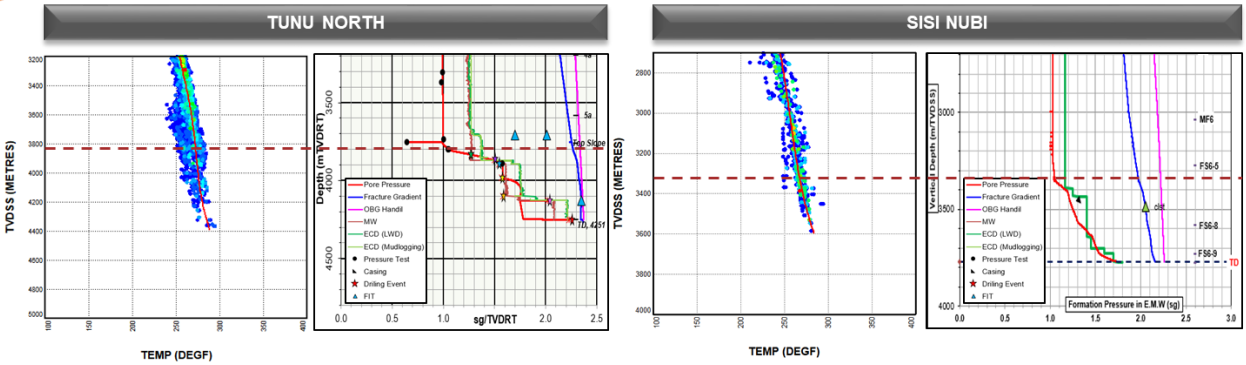


Figure 9. Formation temperature profile at overpressure interval in Tunu North and Sisi Nubi fields.

4 Conclusions

Temperature profiles of Mahakam fields are not linear. Each field has unique temperature profile. The formula of non-linear formation temperature profile in Mahakam fields has been derived by using quantic (5th degree) polynomial regression as a function of depth. By having more accurate temperature profile, it will improve accuracy of subsurface works which require formation temperature data. The non-linearity of temperature profile is mainly caused by lithology (NTG ratio) as sandstone has significantly higher thermal conductivity than shale and coal. Less effect of overpressure zone on temperature. It's probably due to well consolidated rocks that giving less contrast between sandstone and shale.

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