CHAPTER 4

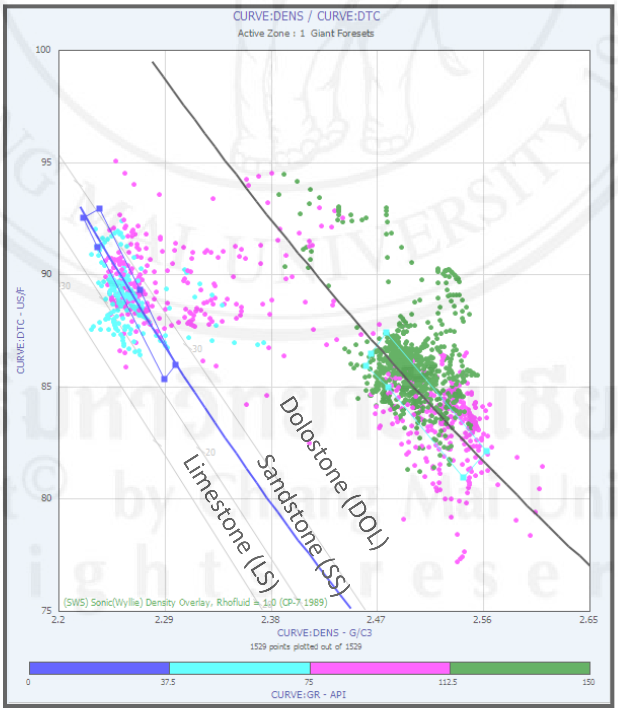
WELL LOG CONDITIONING

Due to the absence of sonic logs in some wells and wash-outs in certain intervals, we have to estimate logs in some wells. One way to do this is to use empirical relationships that transform one physical parameter to another. In this case, we chose a form of the Wyllie relation to convert density to P-sonic (slowness). The idea is to cross-plot sonic *versus* density in another well (the model well) with the aim of finding a relationship between these two parameters. This stage was done using Interactive Petrophysics (IP) software. The cross-plot is overlain by Wyllie lines. These lines, in IP software, consist of three lines referring to the lithology of sandstone, dolostone, and limestone. The interpretation zone is made in the cross-plot, trying to follow the Wyllie line guided by Gamma Ray. In case the corresponding lithology is present, ideally the trend should be parallel with the lithology line. In reality, however, the trend might have different gradient by the presence of more than one lithology in one formation. Based on the data inside the zone previously created, the regression line is shown and the equation is calculated. The equation will then be used to predict the sonic log in another well.

Considering the reliability of the well logs and the presence of formations that need to be predicted, Kahu-1 and Amokura-1 were chosen to be the model wells. The equations estimated will be based on Kahu-1 or Amokura-1, depending on the available formations in the wells. The equation would be calculated based on each particular formation, to make sure that the estimation that made is as close to the log values in the new well as possible. Every formation is expected to have its own physical characteristics.

a. Moki A Sandstone

Figure 4.1 shows the cross-plot of sonic and density logs in the Moki A Sandstone in Amokura-1. The data points are separated into two clusters. The first one is that having low Gamma Ray associated with sand (blue and magenta points) while the other is of having high Gamma Ray associated with shale (green and magenta points). Therefore, we should define two zones in this formation. Assuming regressions of the form DTC = a*DENS^b, the blue and black curves represent the regressions of sand and shale, respectively. Each curve has an equation that estimates the sonic log (slowness). To apply these equations, a cut-off value is needed. In this case, a Gamma Ray cut-off of 85 is used. The Gamma Ray cut-off chosen here seems to be high for sand-shale separation. However, the chosen value gives a closer DTC log estimate of the original DTC (Figure 4.2: track 6) than other trial cutoffs. This probably indicates that sand lithology in the Moki A formation is more likely to be shaly sand. The black line is the predicted log while the magenta is the original one in track 6.



Blue line : Sand trend
Black line: Shale trend

Figure 4.1. Sonic-density crossplot coloured by Gamma Ray in Moki A Sandstone in Amokura-1

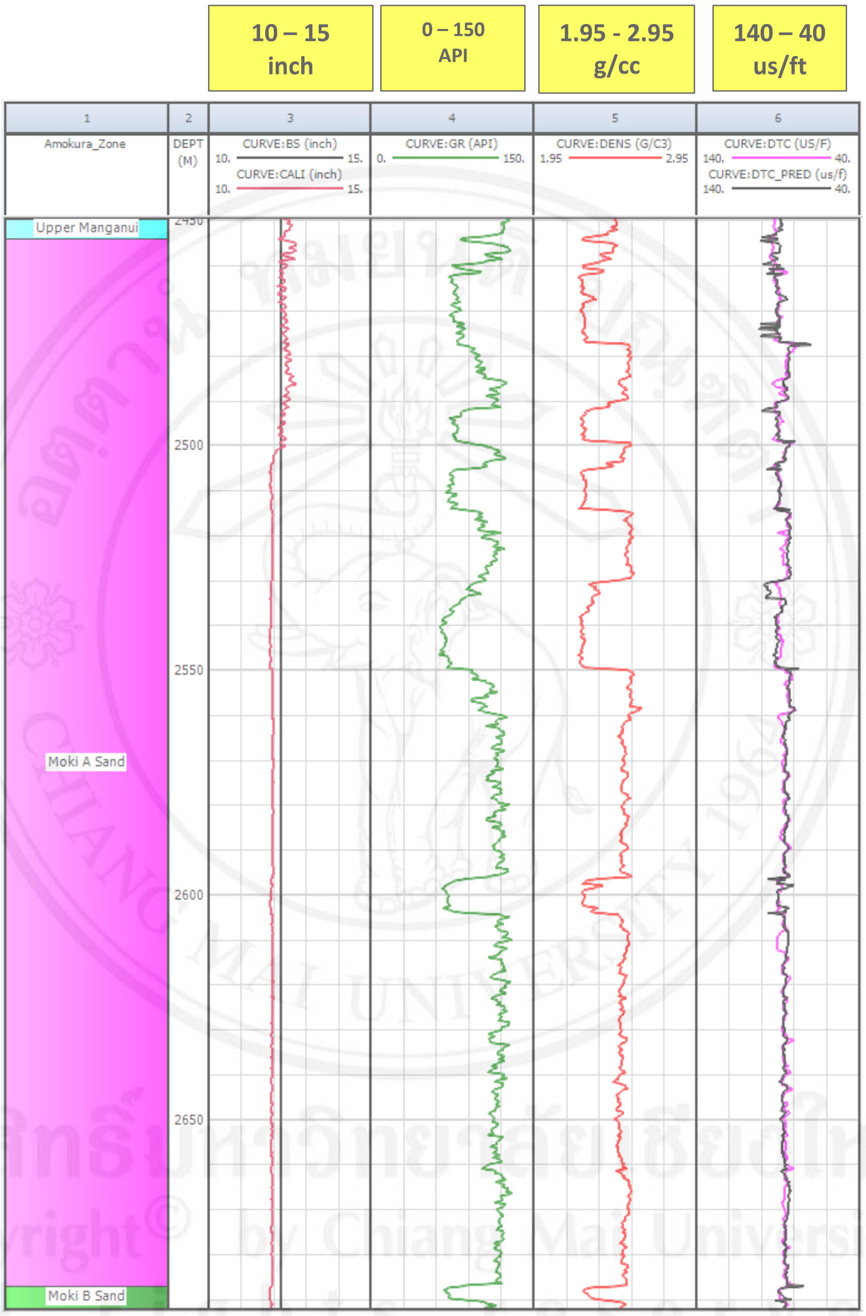


Figure 4.2. The logs of Amokura-1 specifically in the Moki A Sandstone. Track 1: Name of formation; Track 2: Measured depth; Track 3: Bit size (black), Caliper (red); Track 4: Gamma Ray; Track 5: Density; Track 6: Original sonic (magenta), estimated sonic (black)

The equations are as follows.

$$DTC = 344.795 * DENS^{\wedge} - 1.66127$$ **Sand**

$$DTC = 260.561 * DENS^{\wedge} - 1.22314$$ **Shale**

DTC : Sonic P-slowness (µs/ft)

DENS : Density (g/cm^3)

**Noted: three digits are considered significant*

b. Moki B Sandstone

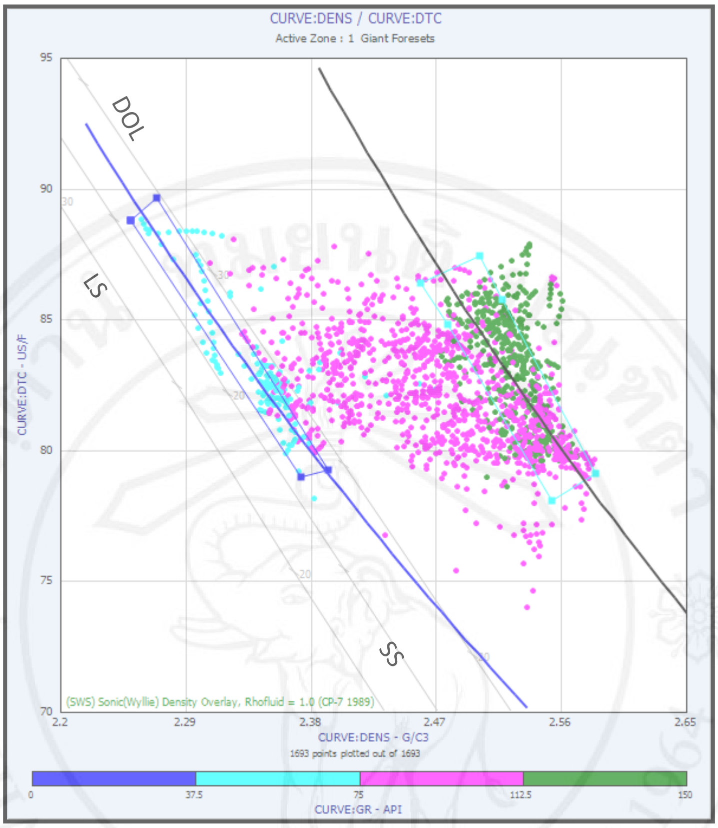
Figure 4.3 shows the cross-plot of sonic-density in the Moki B Sandstone in Amokura-1. The data points here are even more scattered than the previous formation. To simplify, two zones were made in the area of highest gamma ray and in the lowest one. In this case a gamma-ray cut–off of 75 was used resulting the log estimation close enough to the original log. The DTC log estimation can be seen in Figure 4.4-track 6.

The two regression curves representing the created zonation came up with the following equation.

$$DTC = 499.395 * DENS^{\wedge} - 2.10566$$ **Sand**

$$DTC = 609.132 * DENS^{\wedge} - 2.15742$$ **Shale**

**Noted: three digits are considered significant*



Blue line : Sand trend
Black line: Shale trend

Figure 4.3. Sonic-density crossplot coloured by gamma ray in Moki B Sandstone in Amokura-1.

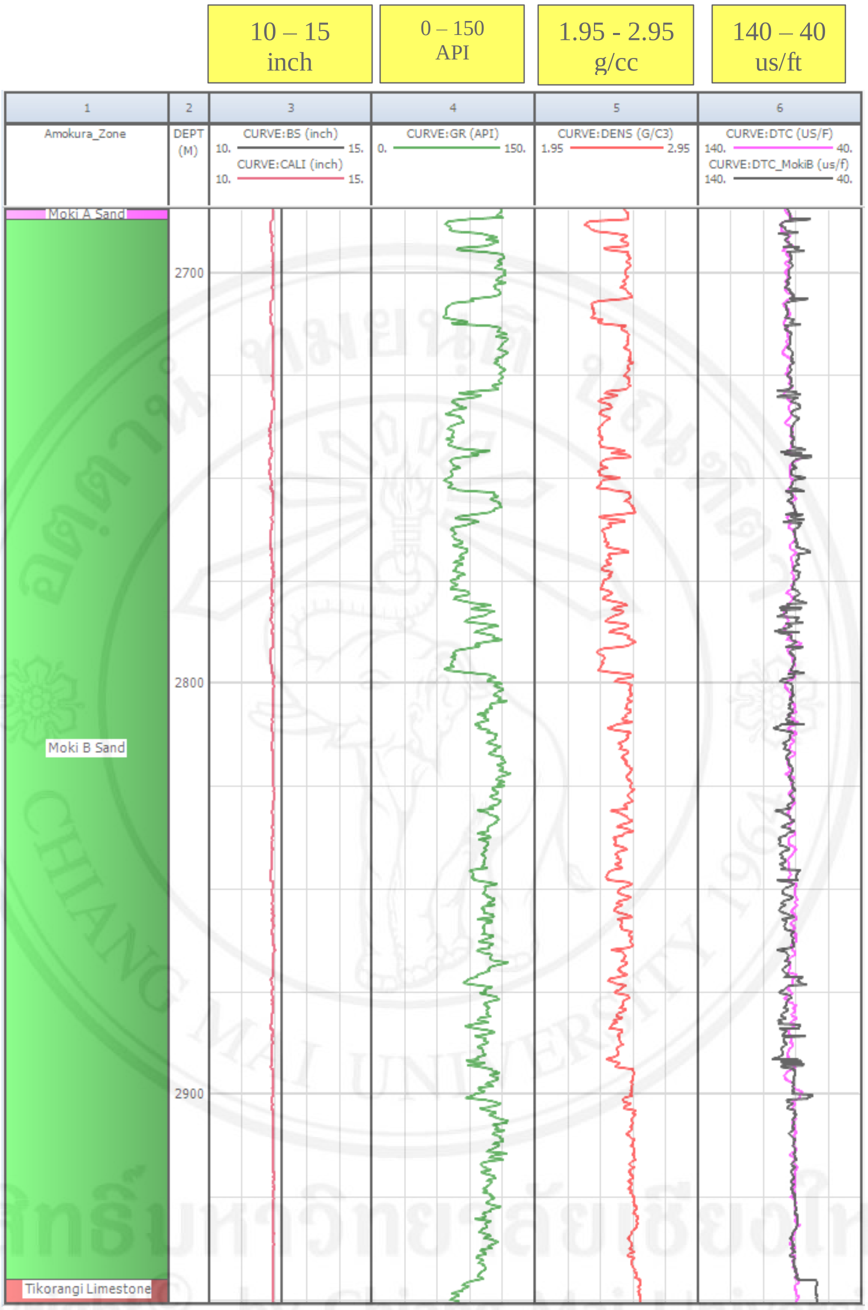


Figure 4.4. The logs of the Moki B Sandstone in Amokura-1. Track 1: Name of formation; Track 2: Measured depth; Track 3: Bit size (black), Caliper (red); Track 4: Gamma Ray; Track 5: Density; Track 6: Original sonic (magenta), estimated sonic (black).

c. Tikorangi Limestone

The sonic-density cross-plot of the Tikorangi Limestone in Kahu-1 is shown in Figure 4.5. The characteristics of this limestone formation, which are quite different from the other formations, are shown in the cross-plot. Most of the data are align along one trend. Hence, one regression curve is enough to represent the data. Ideally the limestone trend should be parallel to the limestone line. However, some other lithology may be present in this formation causing the trend of the data not parallel. Therefore, trial error of making zonation was done to get optimum estimated log close to the original but not crossing the lithology line. As seen in the Figure 4.6:track 6 of the logs, the predicted sonic log (black) follows the trend of the original one (magenta).

The sonic-density relationship is shown in the following equation.

$$DTC = 11552.4 * DENS\hat{} - 5.28127$$

As a comparison, a linier trend of regression line following a visual data trend was shown in Figure 4.5b.

$$DTC = 708.944 - 244.781 * DENS$$

**Noted: three digits are considered significant*

As it can be evaluated from the Figure 4.6:track 7, though the the estimated result looks following the linier trend, it seems that the estimated log here is more ringy (small fluctuation) in comparison to the previous estimation. In fact the actual log is actually smooth. Therefore the former estimation was chosen as qualitatively showing a better estimation.

a.

b.

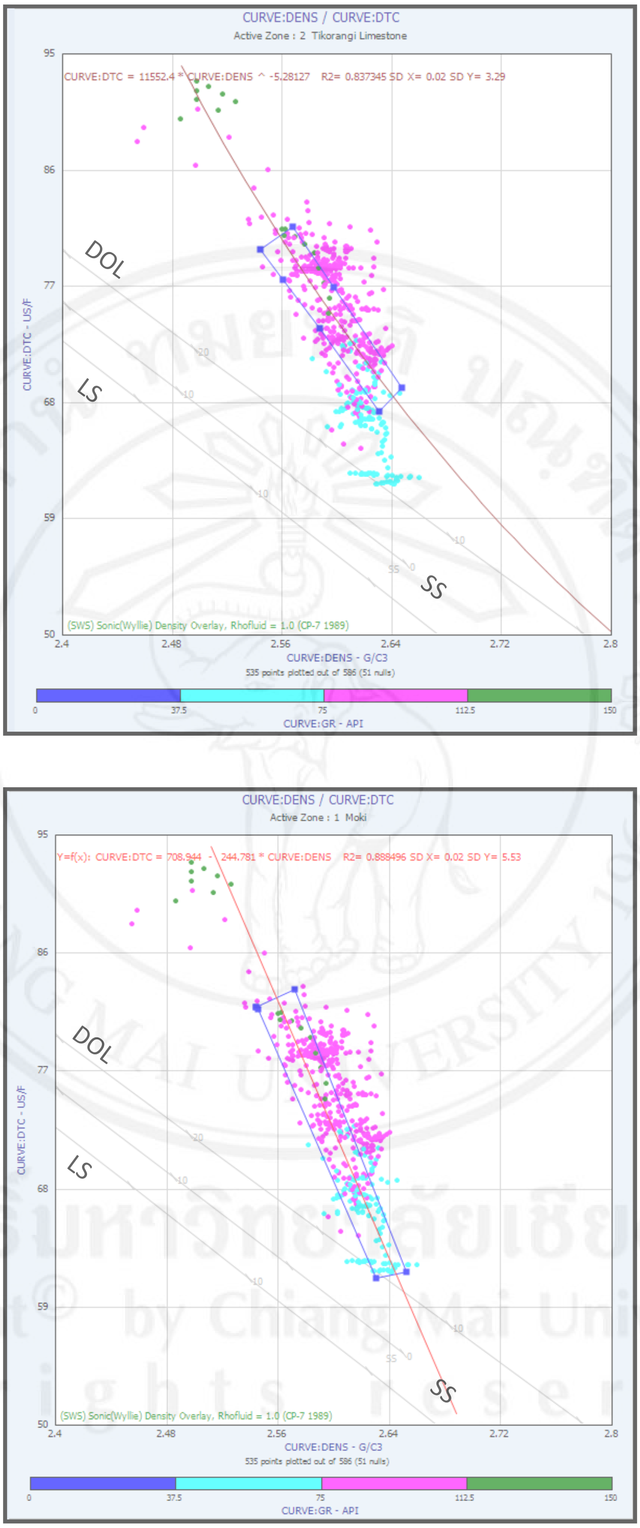


Figure 4.5. Sonic-density crossplot coloured by Gamma Ray in Tikorangi Limestone in Kahu-1

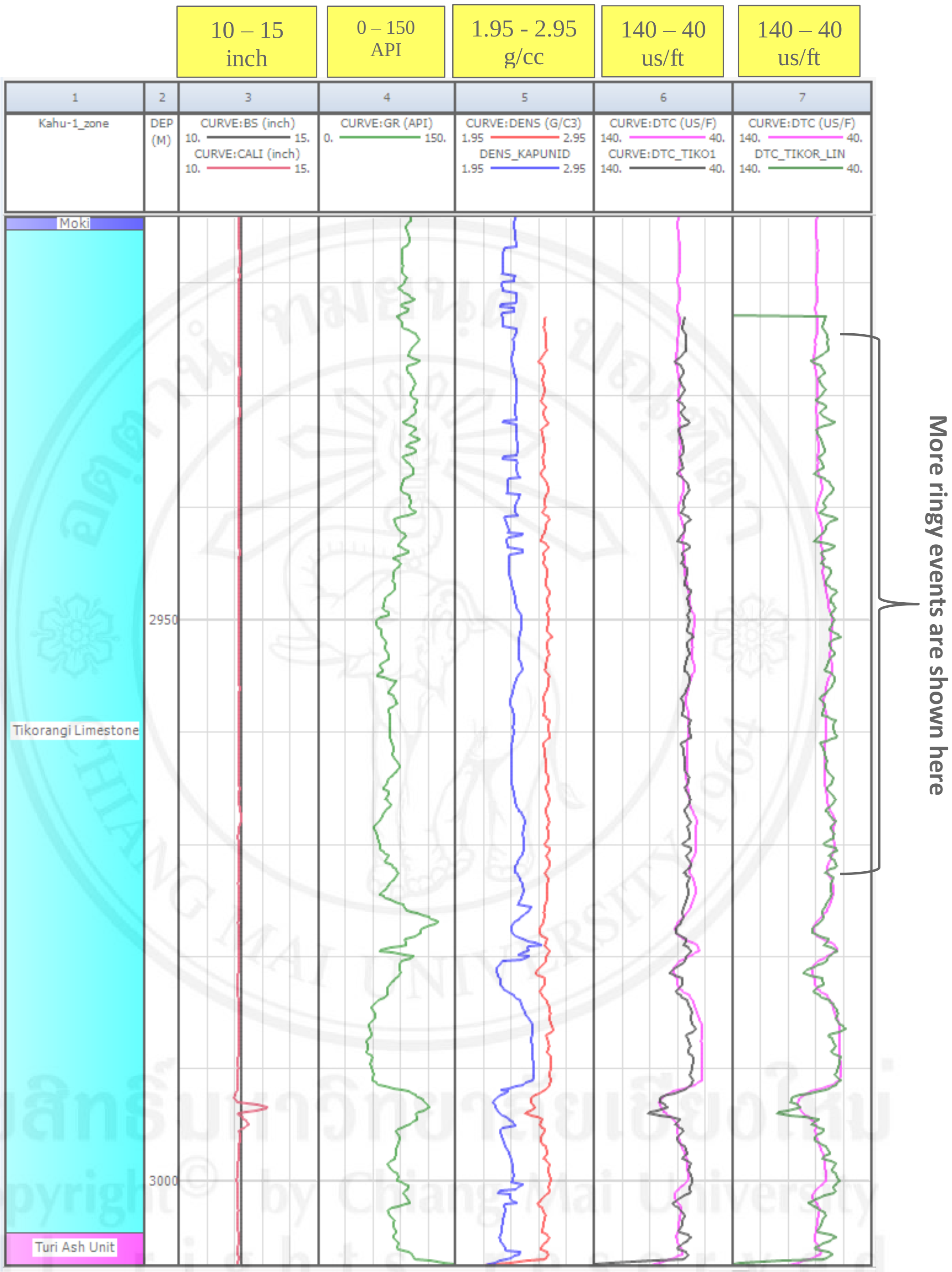


Figure 4.6. The logs of the Tikorangi Limestone in Kahu-1. Track 1: Name of formation; Track 2: Measured depth; Track 3: Bit size (black), Caliper (red); Track 4: Gamma Ray; Track 5: Density; Track 6: Equation 1 - Original sonic (magenta), estimated sonic (black); Track 7: Equation 2 - Original sonic (magenta), estimated sonic (green).

d. Turi Ash Unit

The following Figure 4.7 shows the relationship between the sonic and density logs in the Turi Ash Unit in Kahu-1. Determining the trend of this particular formation is a quite challenging due to its low thickness marked by less data points (about 58 m only according to well report). The regression curve in brown shows the optimum trend for generating a relatively accurate log estimation (track 6).

The equation for this formation is as follows.

$$DTC = 201.987 * DENS^{\wedge} - 0.825264$$

**Noted: three digits are considered significant*

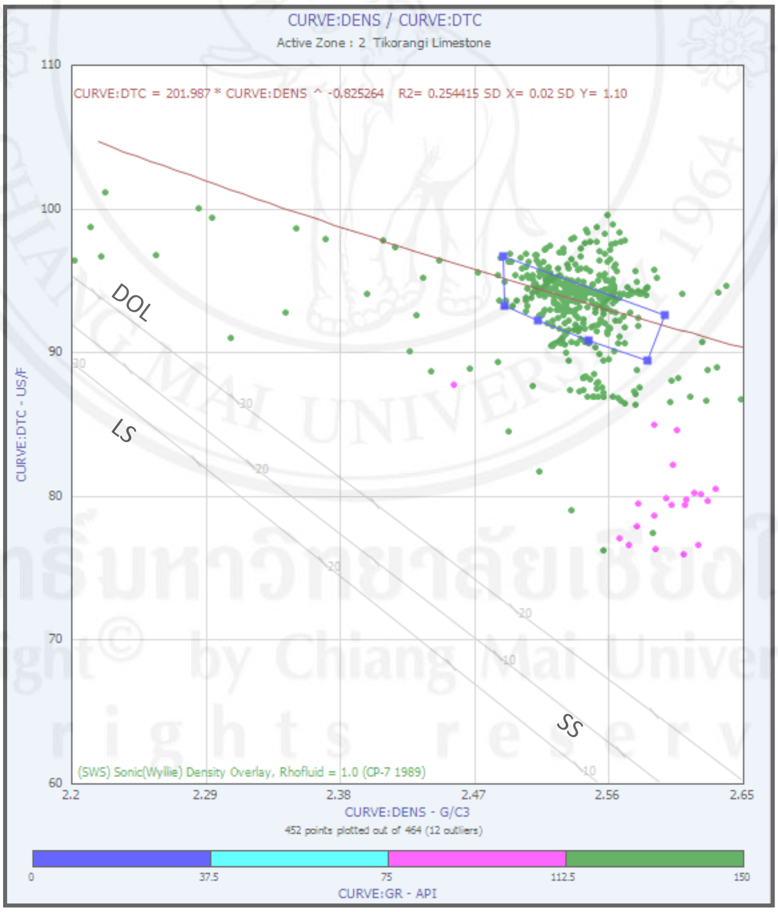


Figure 4.7. Sonic-density crossplot coloured by Gamma Ray in Turi Ash Unit in Kahu-1.

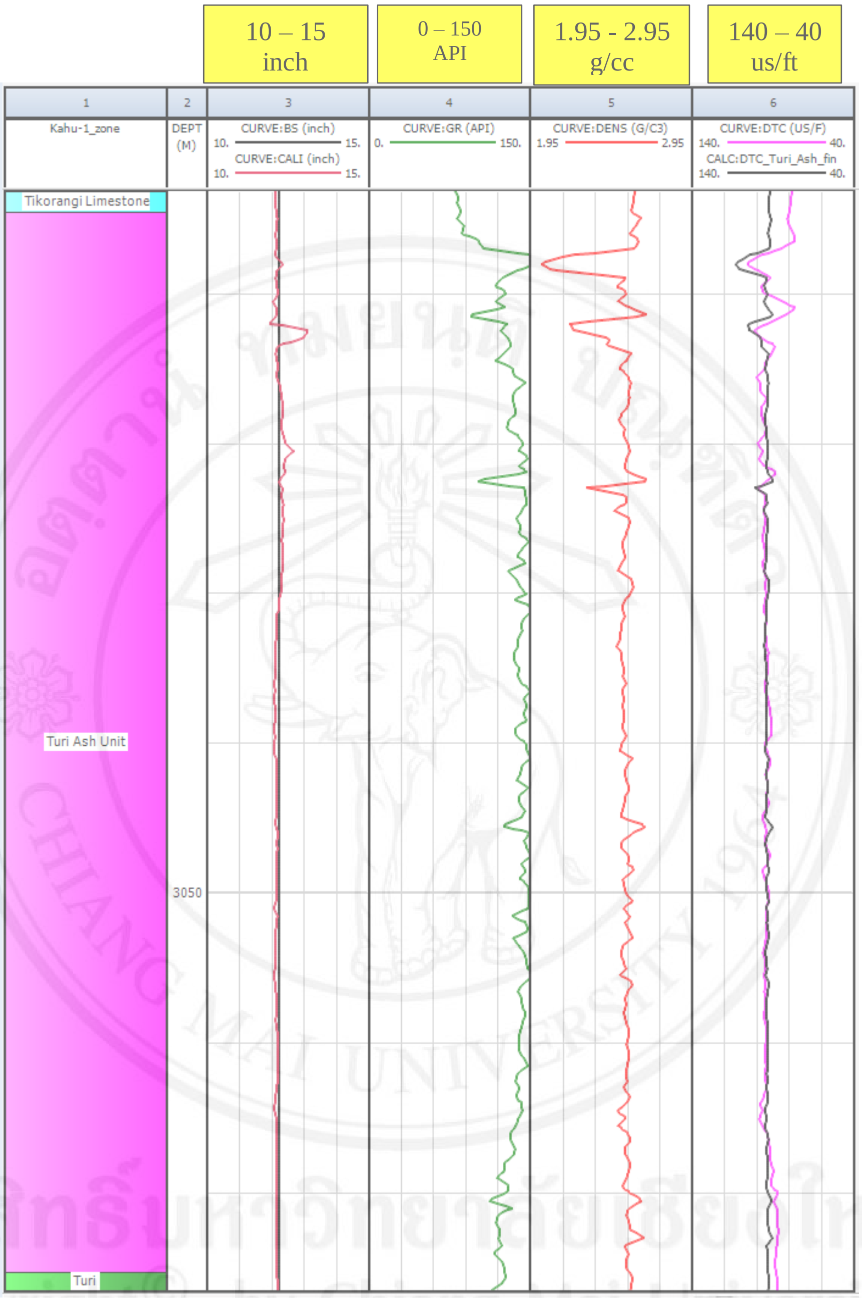


Figure 4.8. The logs of the Turi Ash Unit in Kahu-1. Track 1: Name of formation; Track 2: Measured depth; Track 3: Bit size (black), Caliper (red); Track 4: Gamma Ray; Track 5: Density; Track 6: Original sonic (magenta), estimated sonic (black).

e. Turi Formation

Below (Figure 4.9) we show the sonic-density relationship of the Turi formation in Kahu-1. Though some spurious data are identified, the trend of the data is quite clear. The brown regression line indicates the optimum trial line to get a relatively accurate prediction. Hence, one zone has been drawn following the general trend resulting the equation as follows.

$$DTC = 1918.67 * DENS^{\wedge} - 3.33122$$

**Noted: three digits are considered significant*

As a comparison, the linier trend crossing the guided Wyllie line was tried. Though this linier trend seems to represent the trend of the data visually, the result shows this estimation generates many artificial spikes which do not exist in the real log (Figure 4.10:track7). The equation for this trial is written as follows.

$$DTC = 646.159 - 219.415 * DENS$$

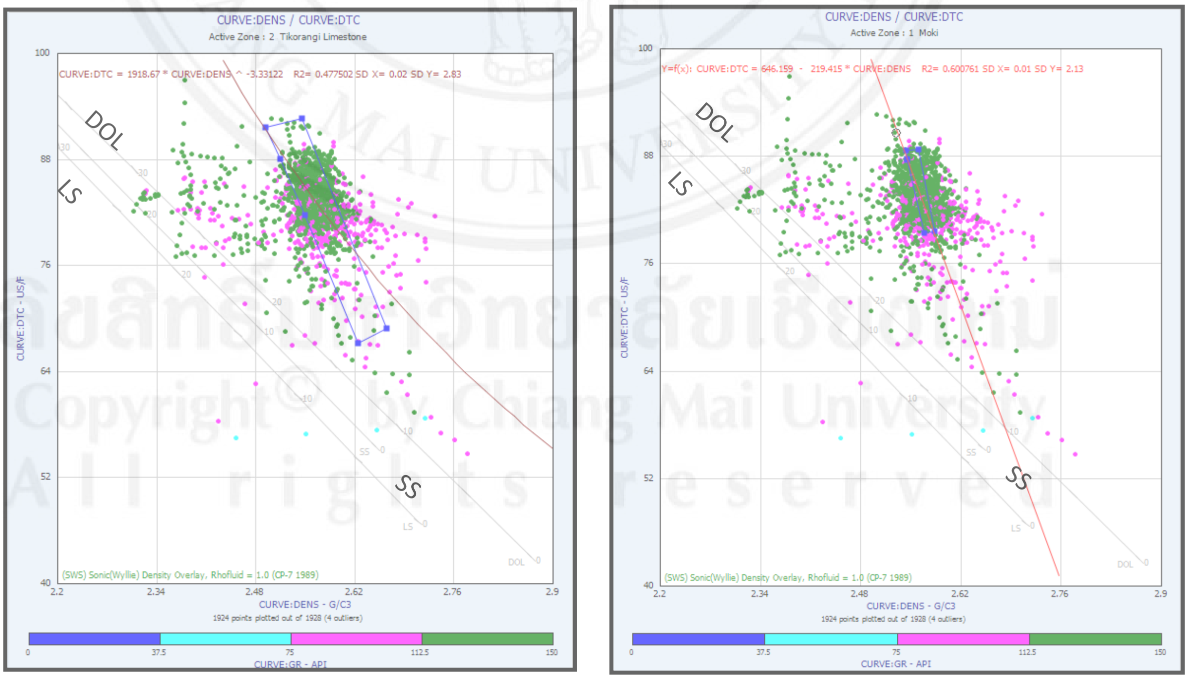


Figure 4.9. Sonic-density crossplot coloured by Gamma Ray in Turi Formation in Kahu-1.

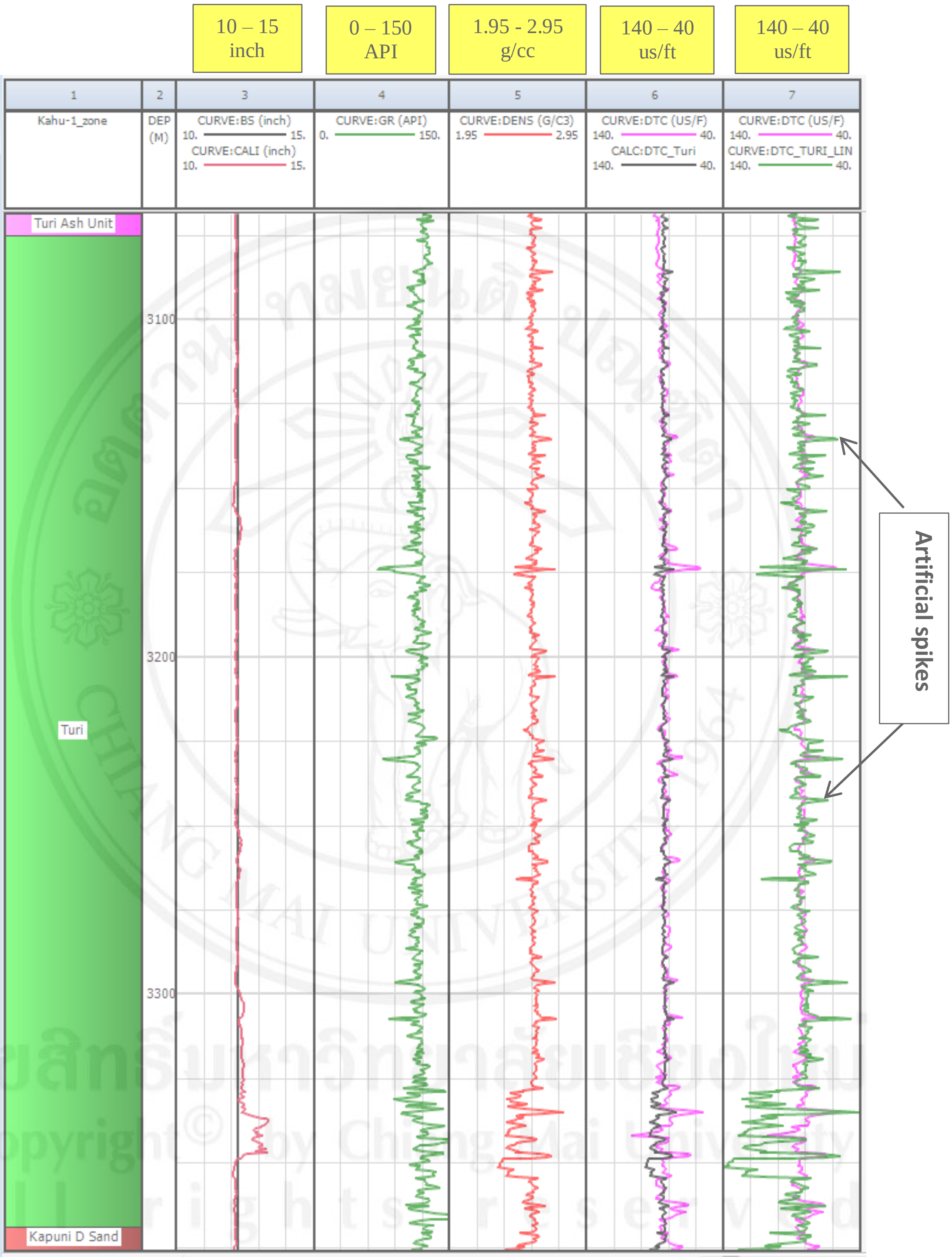


Figure 4.10. The logs of the Turi formation in Kahu-1. Track 1: Name of formation; Track 2: Measured depth; Track 3: Bit size (black), Caliper (red); Track 4: Gamma Ray; Track 5: Density; Track 6: Equation 1 - Original sonic (magenta), estimated sonic (black); Track 7: Equation 2 - Original sonic (magenta), green sonic (green).

f. Kapuni D Sandstone

Figure 4.11 shows the relationship of sonic-density in the Kapuni D Sandstone in Kahu-1. As seen in the gamma ray log Figure 4.12:Track 6, the gamma ray log fluctuates considerably indicating interbedded sand and shale in this formation. Hence, dividing the zone into two clusters is essential. Moreover, it seems the zone of sand and zone of shale are quite distinguishable. This results in two regression curves.

$$DTC = 609.326 * DENS^\wedge - 2.46257 \quad \textbf{Sand}$$

$$DTC = 666.994 * DENS^\wedge -2.4594 \quad \textbf{Shale}$$

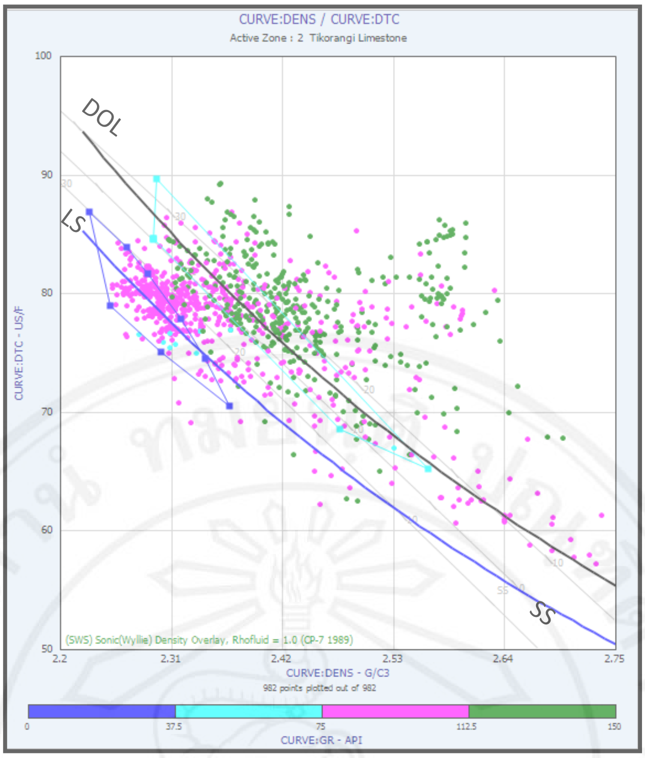
**Noted: three digits are considered significant*

This formation uses the gamma ray cut-off of 95 for optimum result. The result in Track 6 shows the predicted sonic log match with the actual log pretty well. Another important thing to mention is that the washout zone in Tui-1 well occurred in Kapuni D Sand which is the reservoir zone. Therefore, in addition to sonic, there is a need to estimate the density log as well. Figure 4.12 shows the crossplot for estimating density which is simply the reciprocal of the previous crossplot. The result of density estimation can be seen in Figure 4.13: track5. The following are the equations taken from the regression line both sand and shale.

$$DENS = 12.2591 * DTC^\wedge -0.384169 \quad \textbf{Sand}$$

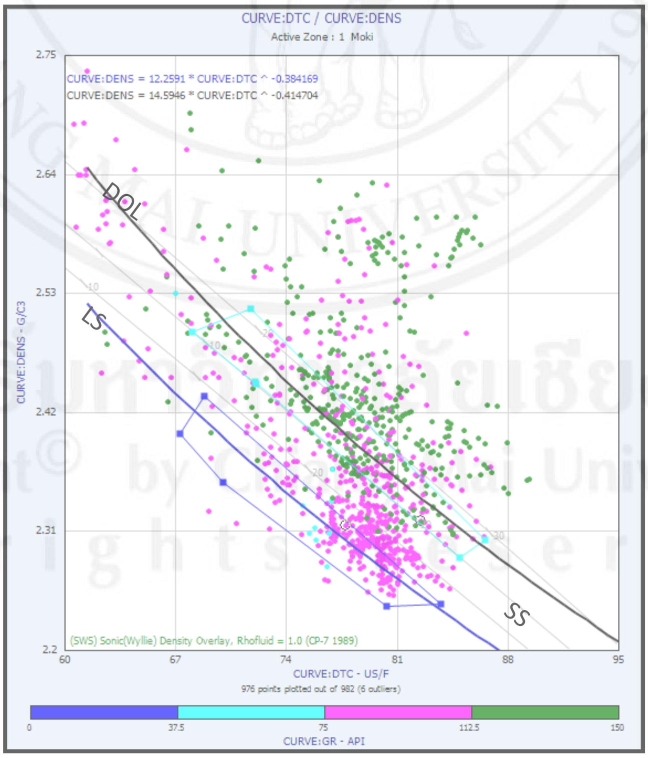
$$DENS = 14.5946 * DTC^\wedge -0.414704 \quad \textbf{Shale}$$

**Noted: three digits are considered significant*



Blue line : Sand trend
Black line: Shale trend

Figure 4.11. Sonic-density crossplot coloured by Gamma Ray in Kapuni D Sandstone in Kahu-1.



Blue line : Sand trend
Black line: Shale trend

Figure 4.12. Density-sonic crossplot coloured by Gamma Ray in Kapuni D Sandstone in Kahu-1.

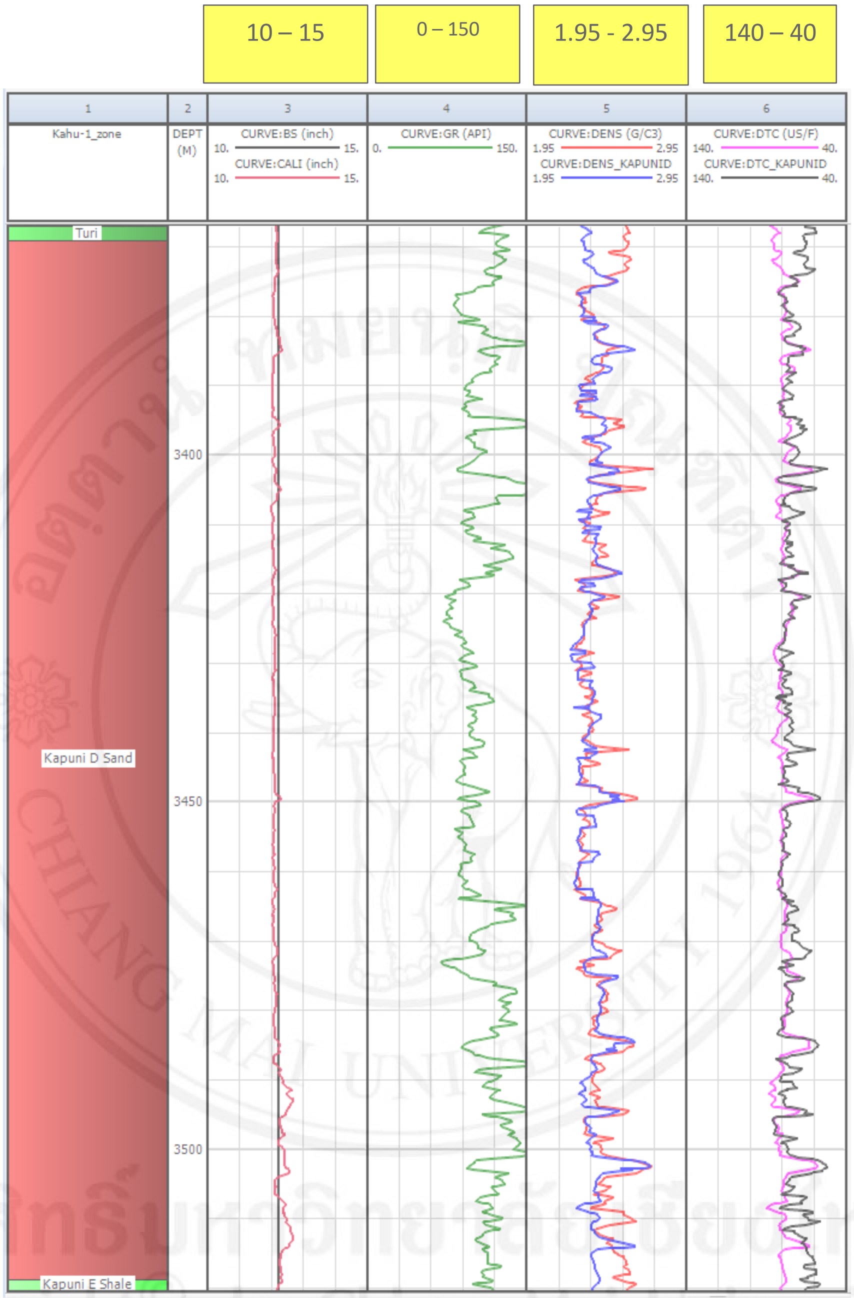


Figure 4.13. The logs of the Kapuni D Sand in Kahu-1. Track 1: Name of formation; Track 2: Measured depth; Track 3: Bit size (black), Caliper (red); Track 4: Gamma Ray; Track 5: Original density (red), estimated density (blue); Track 6: Original sonic (magenta), estimated sonic (black).

g. Kapuni E Shale

The sonic-density cross-plot for Kapuni E Shale in Kahu-1 is shown in Figure 4.14. From composite log, it is known that the thickness of the bed is relatively thin just about 50m. It makes it hard to see the trend on the crossplot. Trial and error method was used to define the zone. The regression curve in brown is a predicted representation of the trend.

$$DTC = 349.996 * DENS^{\wedge} - 1.60179$$

**Noted: three digits are considered significant*

The result of the estimation can be seen in Figure 4.15:track 6. A few small intervals cannot be matched but log prediction in most of the interval gives a relatively close result.

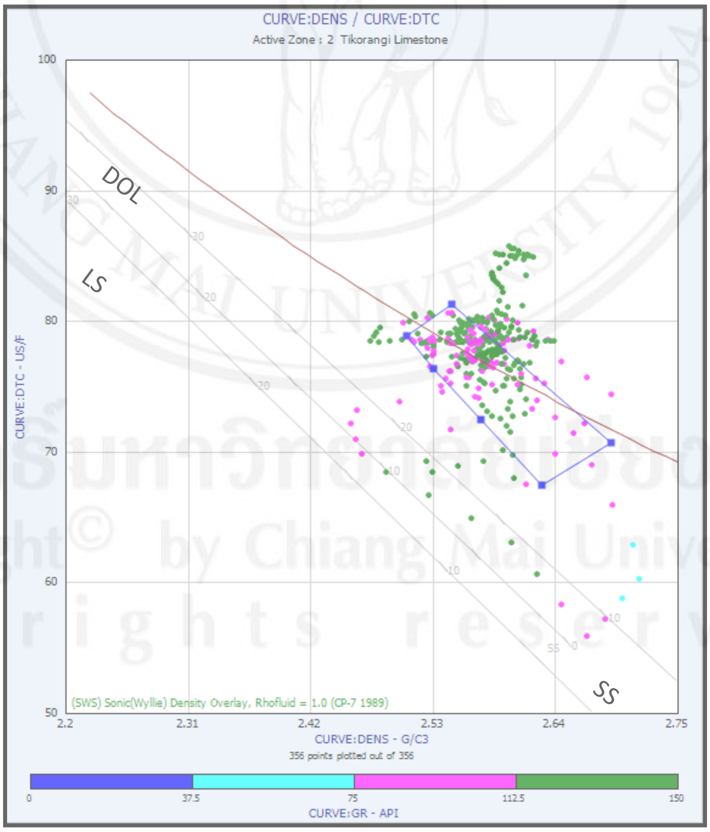


Figure 4.14. Sonic-density crossplot coloured by Gamma Ray in Kapuni E Shale in Kahu-1.

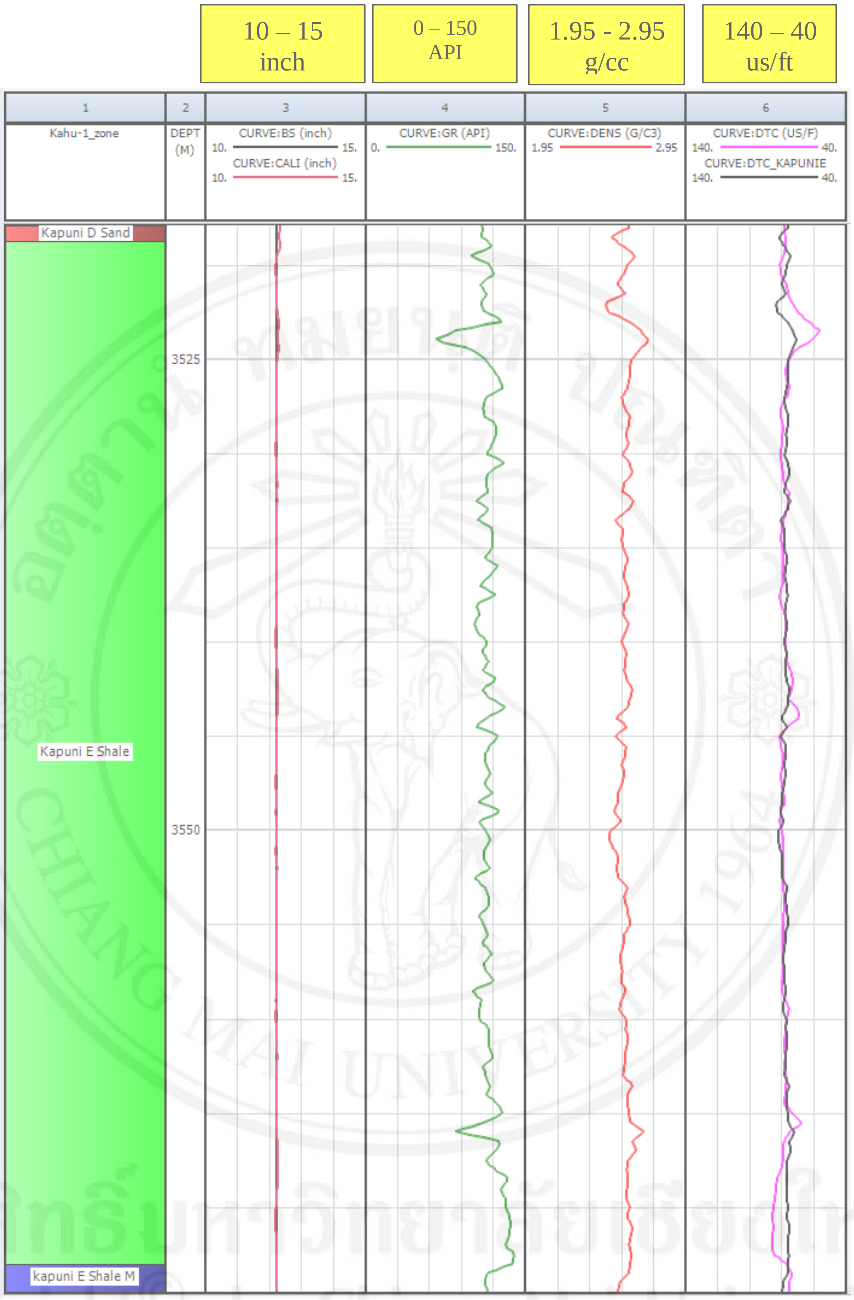


Figure 4.15. The logs of the Kapuni E Shale in Kahu-1. Track 1: Name of formation; Track 2: Measured depth; Track 3: Bit size (black), Caliper (red); Track 4: Gamma Ray; Track 5: Density; Track 6: Original sonic (magenta), estimated sonic (black).

h. Kapuni F Sandstone

Figure 4.16 shows the sonic-density relationship in the main reservoir, the Kapuni F Sandstone, in Kahu-1. Small fluctuations of the gamma-ray log in track 4 indicate the presence of thin shale interbedded with sand. Looking closely at the data distribution in the cross-plot, most of the sand is overlapped by shale. The sand-shale zone was then defined by assuming that sand has lower density than shale. The following are the equations used for log prediction.

$$DTC = 491.357 * DENS\text{^} - 2.23838 \quad \textbf{Sand}$$

$$DTC = 489.798 * DENS\text{^} - 2.16329 \quad \textbf{Shale}$$

**Noted: three digits are considered significant*

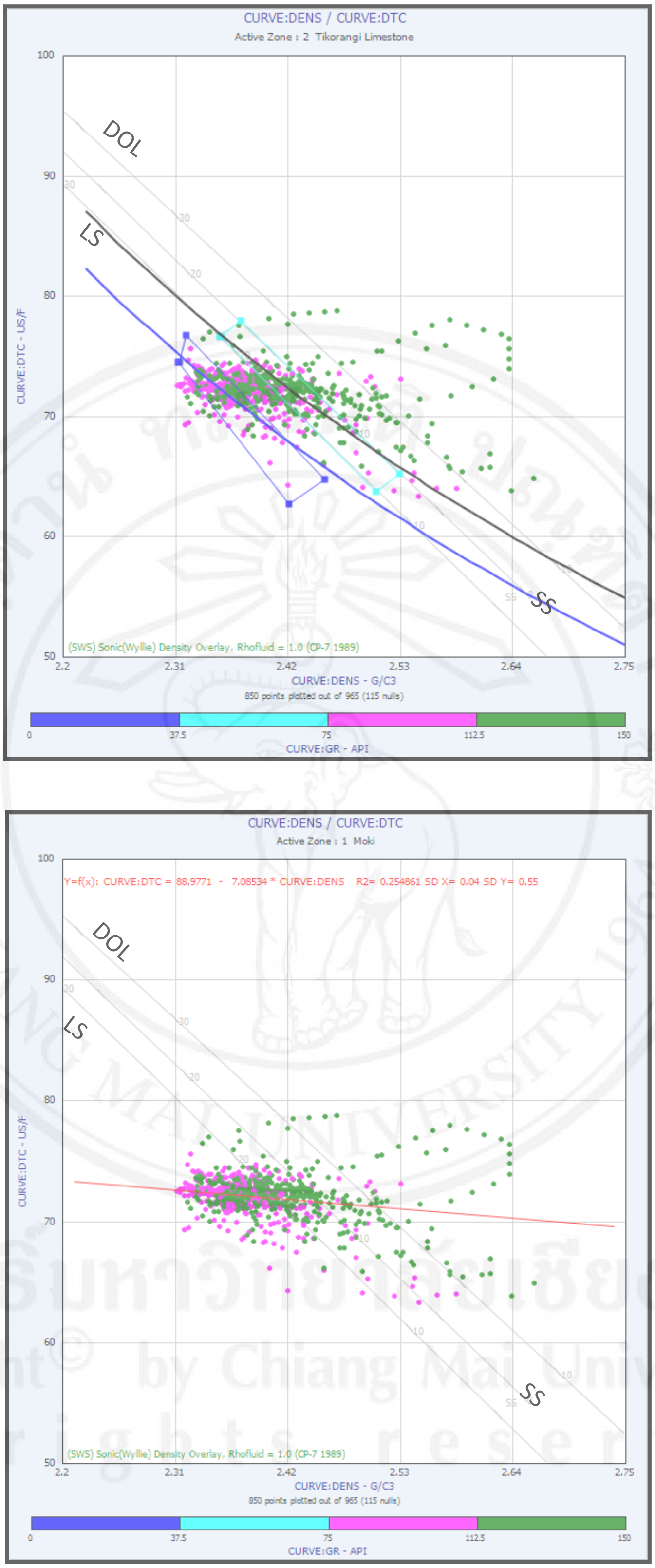
The result of estimation shown in Figure 4.17:track 6, confirming the zonation made is quite reasonable just by looking qualitatively the matching between the original and the estimated one.

In addition to that, the linier trend of the data which is almost horizontal was shown as a comparison (Figure 4.16b). However, the result shows that this particular trend is far from the original as showing almost no variation along the formation. The result can be seen in Figure 4.17:track 7. The equation used to generate the log is shown as follow.

$$DTC = 88.9771 - 7.08534 * DENS$$

a.

b.



Blue line : Sand trend
Black line: Shale trend

Figure 4.16. Sonic-density crossplot coloured by Gamma Ray in Kapuni F Sandstone in Kahu-1.

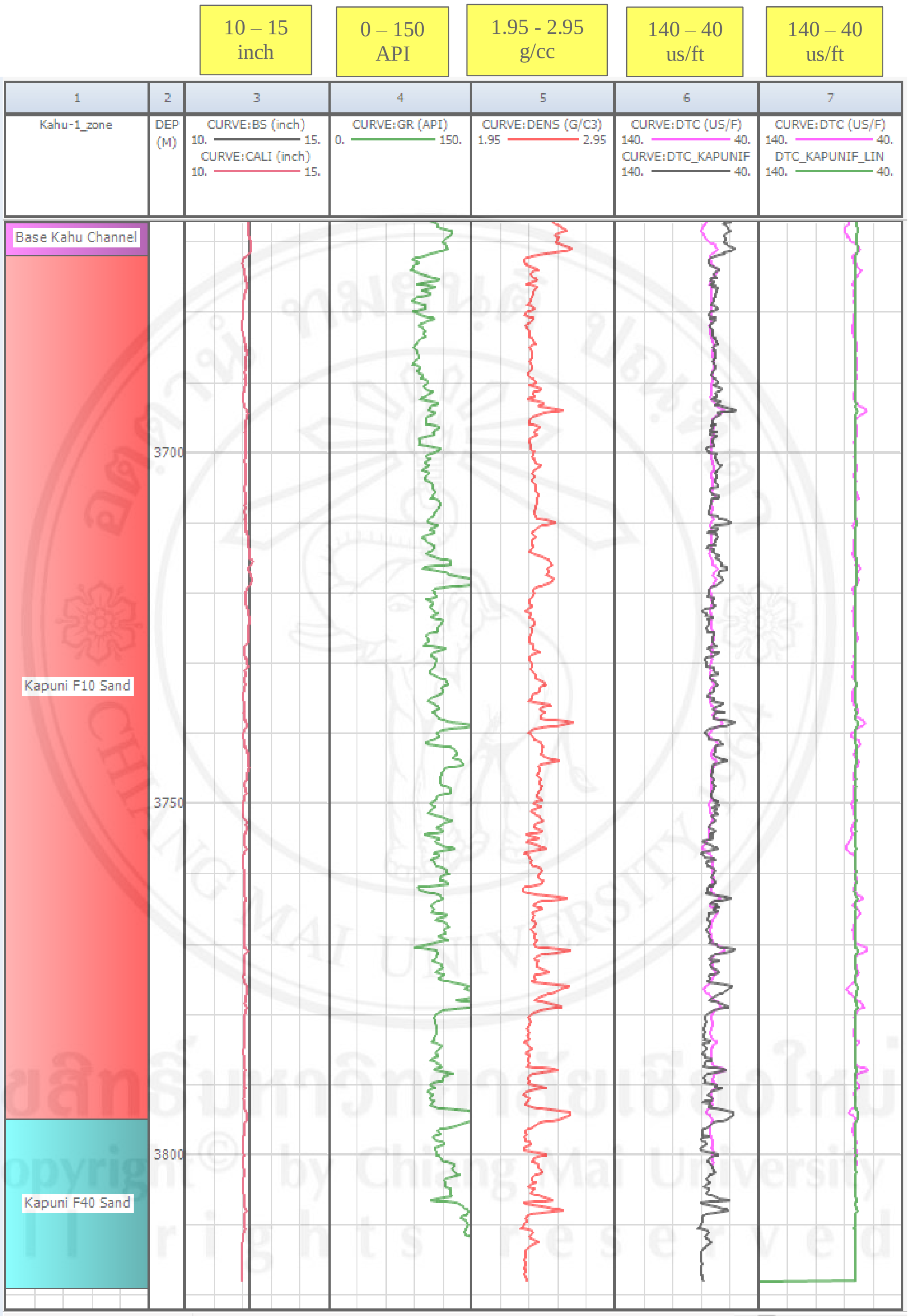


Figure 4.17. The logs of the Kapuni F Sand in Kahu-1. Track 1: Name of formation; Track 2: Measured depth; Track 3: Bit size (black), Caliper (red); Track 4: Gamma Ray; Track 5: Density; Track 6: Equation 1 - Original sonic (magenta), estimated sonic (black); Track 7: Equation 2 - Original sonic (magenta), green sonic (green).