Petrophysical Relationship to Predict Synthetic Porosity Log*

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Abstract

In seismic analysis, P-waves are an important attribute to identify the reservoir. It is sensitive with the presence of hydrocarbon either gas or oil. By petrophysical relationship, the synthetic log can be estimated. Faust's equation was used to obtain P-wave velocity based on resistivity value. Gardner's equation was used to derive P-wave becomes density. Because the porosity of a reservoir could be obtained based on resistivity and density, the log transformation method could be used to estimate the porosity log. In this research, log transformation method was used so that the synthetic log porosity in reservoir characterization with a depth of 5,500 ft could be estimated. When the P-wave velocity log was estimated by Faust's equation, a better result was obtained at a depth of 4,300 - 5,479 ft compared with the measured P-wave velocity. A good result was also obtained by the conversion of P-wave velocity to density at a depth of 4,216 - 5,475 ft. The conclusion is porosity log transform might be valid at a depth of 4,300 - 5,400 ft.

Introduction

Indonesia has many old oil fields, which do not have complete log parameters as a modern field. The logs of those old oil fields were recorded manually so it provides quite limited information. Today the energy demand is increasing more and more. Covering the energy demand, production of hydrocarbon is expected to increase. Many alternative solutions appear to cover the energy need; one of them is evaluating the old field, which does not produce hydrocarbons anymore. The problem is a complete log is needed to decide weather that old oil field can produce again but the fact is there is just a few log available. If we want to get the complete log data, high-cost modern logging must be done. Trying to reduce the cost, an unknown log actually can be estimated from another using a petrophysical relationship. This research provides a prediction of a log from several logs, which are known.

Some important rock physics parameters related to the storage capacity, fluid flow capacity, and amount of hydrocarbon pore volume are porosity, permeability, and saturation. In the case of there are no porosity and permeability data the calculation becomes difficult. If there is resistivity data, those parameters can be estimated using the petrophysical relationship. The empirical relation can be applied to get the density and P-wave velocity log. Log transforms can be used to predict synthetics log such as P-wave velocity, density, and porosity log. Faust predicts

compressional velocities with geological time and depth of burial of the rock, (Faust, 1951). Gardner introduced relation of density and P-wave velocity (Gardner, 1974). The final parameter estimated in this research is porosity. From resistivity data, the synthetic P-wave velocity log can be found using Faust's empirical relation. Synthetic P-wave velocity log used as input data in order to aims estimated density using Gardner's empirical relationship. Finally, porosity log can be estimated from density.

Petrophysical Relation

The science of rock physics addresses the relationships between geophysical observations and the underlying physical properties of rocks such as composition, porosity, and pore fluid content (Mavko, 2009). Most commonly, petrophysics is concerned with the technical evaluation of laboratory data and downhole measurements for reservoir properties such as shale-volume fraction V_{sh}, porosity φ, permeability k, net/gross reservoir, water saturation S_w, and net/gross pay. The subject has a philosophy of indirectness, in that, often, it is not possible to measure a required reservoir property directly. Therefore, it is necessary to measure some other property that is related to the required property. For this reason, petrophysics is built around a framework of interpretive algorithms that relate measurable parameters to reservoir parameters (Worthington, 2011).

Relationship between P-wave and Resistivity

Gassmann (1951) derived an expression for the velocity in a model consisting of tightly packed spherical particles under pressure. The elastic constants of such a pack vary with pressure, and the effect is to make the P-wave velocities vary as the 1/6th power of the pressure. Faust (1953) found an empirical formula for velocity in terms of the depth of burial Z and the formation resistivity R.

$$V_p = a(RZ)^{1/6}$$

(1)

where:

V_p = P-wave velocity (feet/second)
a = constants
R = resistivity value (ohm-feet)
Z = depth (feet)

An earlier form of Faust's law (Faust, 1951) also included the age of the rock as a factor in determining velocity. An older rock might be expected to have a higher velocity, having been subjected for a longer time to pressures, cementation, and other factors that might increase its velocity (Telford, 1990). In many older fields, the only logs that are available are resistivity logs. It has been observed that, in wet clastic rocks, the resistivity log and the P-wave sonic tend to track each other. The Faust's transform can be used to estimate P-wave sonic log, if the P-wave sonic log is missing. However, the method does not account for gas effect (Crain, 2012).

Gardner's Empirical Relationship

There are two ways of deriving P-wave velocity from density. Gardner's equation (Gardner, 1974) is the better known of the two equations. Gardner's equation empirically derived values from a wide range of sedimentary rocks and written as:

$$\rho = aV_p{}^b$$

(2)

where:
ρ = density
V_p = P-wave velocity
a = 0.23
b = 0.25

Density to Porosity

Porosities were determined from the density log by using the following equation (Rider, 1986):

$$\emptyset = \frac{\rho_{ma} - \rho_{obs}}{\rho_{ma} - \rho_f}$$

(3)

where:
ρ_{ma} = matrix density
ρ_{obs} = log density
ρ_j = fluid density

There is some variation in grain density (Table 1). Dolomites can vary from 2.83 to 2.87. Generally, the density tool will read mostly the flushed zone. Recommended density filtrate values are 1.0, 1.1 and 0.90 gr/cc for freshwater, saturated salt water, and oil based muds, respectively (Myers, Gary D., 2007).

Methodology

This research use resistivity, density and V_p from data log. Resistivity used as input data to predict the V_p while real V_p and density as a comparator for the estimation result. Faust's equation was used to estimate V_p from resistivity log. Then, the estimation result was compared

with the real data. Gardner's equation was used to get density. Data used was V_p estimation. As the estimation of V_p, the error value of density was counted. Finally, the resultant density was used to get porosity value.

Examples

This method applied to well log with 700 - 5,500 ft depth. Faust's equation applied to the resistivity log in order to obtain synthetic V_p log. The synthetic V_p log used to aims synthetic density log using Gardner's equation. Then conversion used to estimate the porosity value. Error value for each estimating steps calculated.

Input data used in this research is resistivity as shown in Figure 1a. It has a high resistivity value in a depth range of 1,400 - 2,000 ft. This high resistivity related to the gas effect. A constant value of resistivity appears in the 3,000 - 4,800 ft depth interval. Evaluating a gamma ray log (Figure 1b), we can see the low value between 1,250 - 2,000 ft. It can be related to the presence of sandstone. The resistivity log shows a high value in the same range of depth, which usually related to the existence of gas. Because of that, that depth probably is sandstone contained by gas.

The real V_p data shows by Figure 2a. It has a higher value in the range of 700 – 780 ft depth than another. In the same range of depth, compared with V_p synthetic log by Faust's equation (Figure 2b) the value is so contradictory. In the synthetic log, V_p is lower than another while real data is higher. Synthetic log shows an unstable value from 700 – 3,000 ft depth. After those depths, synthetic V_p is closer with the real value. The real and synthetic data then combined into the same track, it shows the difference clearly as in Figure 3a. The error value from V_p estimated by Faust's equation shown in Figure 3b has an average value of 32.33%.

From those data, error values can be calculated by using similar steps with density error calculation. The error value of density is 9.73 %. Based on synthetic density log by Gardner's equation (Figure 4), the log transformation method was used to estimate the synthetic porosity log (Figure 5c).

The porosity log can be estimated by transforming density. In this research, the real porosity value does not exist so the error value of synthetic porosity log cannot be calculated. Error value counted is error of synthetic V_p and density. Synthetic density log has a smaller error than V_p. Both the V_p and density error value have high error value in the thinner depths. Error value gets smaller with increasing depth. P-wave prediction has an error of 32.33 % and 9.73 % for density. In the depth of 700 - 3,000 ft, V_p estimation deviates from the measured value. In those range of depth, V_p estimation using Faust's equation delivered a higher value. It is caused by the influence of high resistivity and a low gamma ray in that depth, indicating the existence of gas. The Faust's equation cannot work for gas effect (Crain, 2012). Because of that, the error value is going to be high. V_p estimation used as input data in Gardner's equation. The deviation of V_{pest} is influenced in density estimation by Gardner's equation. In the depth 700 – 3,000 ft, the value of density estimation is higher than real density values. When the P-wave velocity log was estimated by Faust's equation, a better result was obtained in a depth of 4,300 - 5,479 ft compared with the measured P-wave velocity. A good result was also demonstrated by the conversion of P-wave velocity to density at a depth of 4,216 - 5,475 ft. The conclusion is porosity log transform might be valid at a depth of 4,300-5,400 ft.

Conclusions

The porosity log can be estimated by transforming density in the case of there are only a few logs available. Error of porosity estimation cannot be calculated because the real data does not exist. Synthetic density log has a smaller error than V_p. Both of V_p and density has a high error value in the thinner depth. It gets smaller with the increasing of depth. P-wave prediction has an error of 32.33 % and 9.73 % for density. Deviation of V_p estimation deviated because Faust's equation does not valid in the presence of gas. A better result of P-wave estimation by Faust's equation obtained in a depth of 4,300 - 5,479 ft. Conversion P-wave velocity to density shows the best result at of 4,216 - 5,475 ft depth. The conclusion is porosity log transform might be valid at a depth of 4,300 - 5,400 ft.

Acknowledgement

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Material	Density (gr/cc)	Fluid	Density (gr/cc)
Quartz	2.65	Fresh Water	1.00
Calcite	2.71	Salt Water	1.15
Dolomite	2.87	Oil	0.85
Anhydrite	2.96		

Table 1. Density of some minerals and fluid.
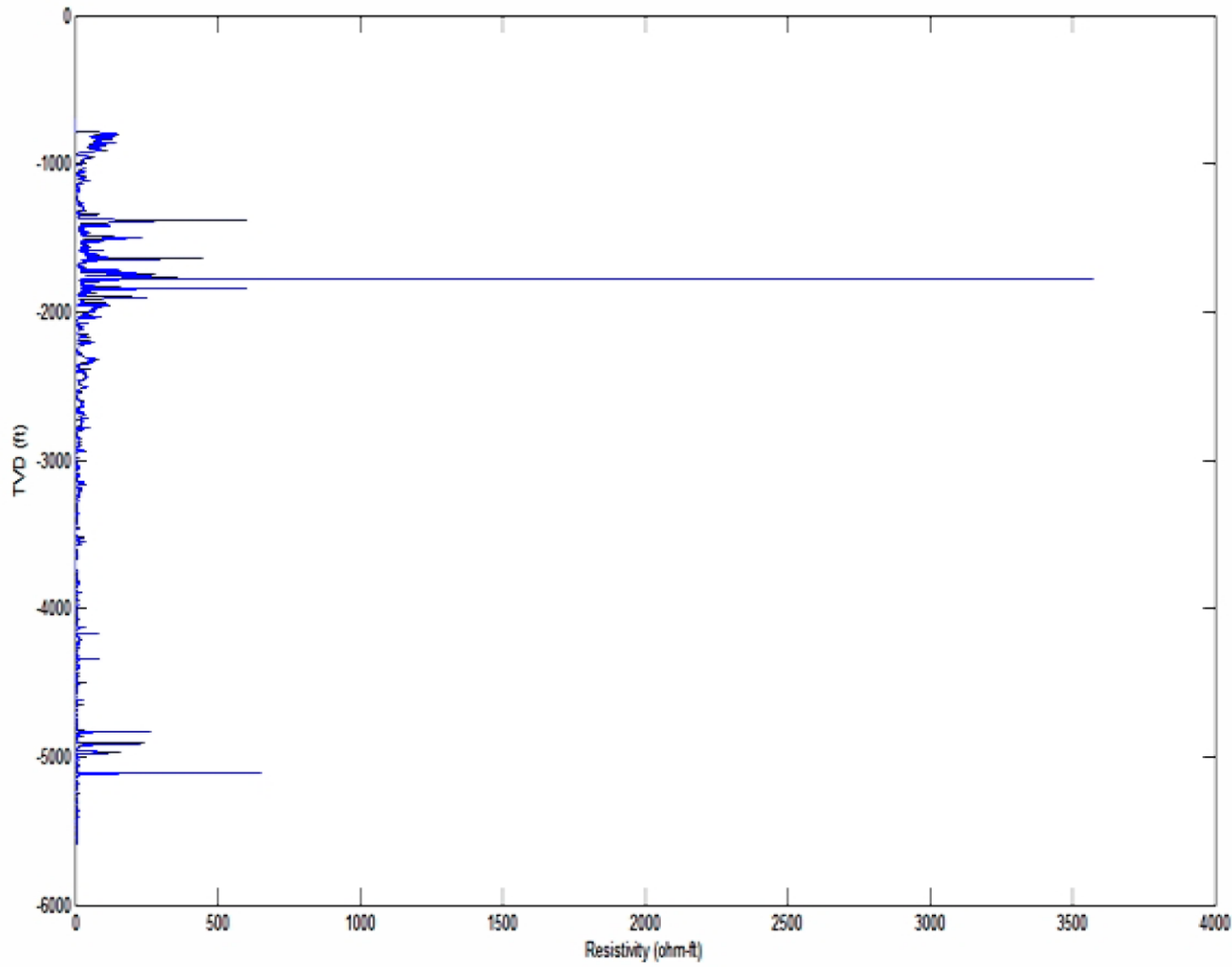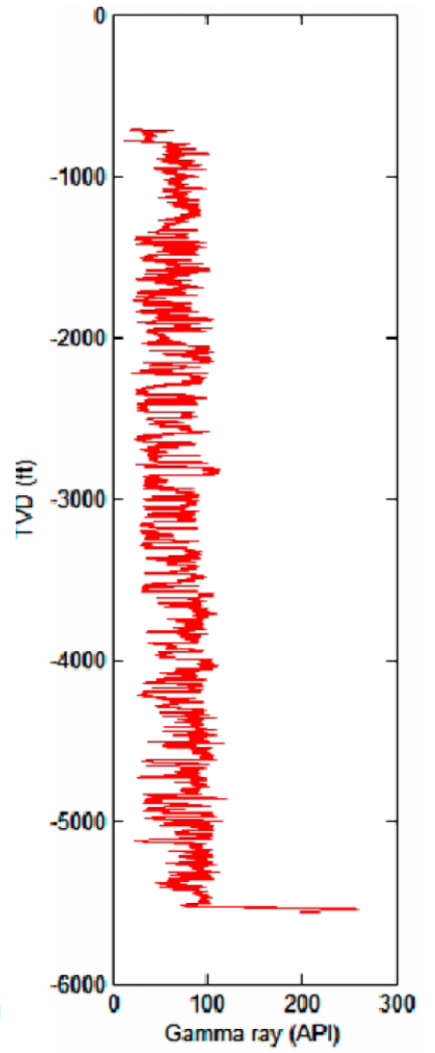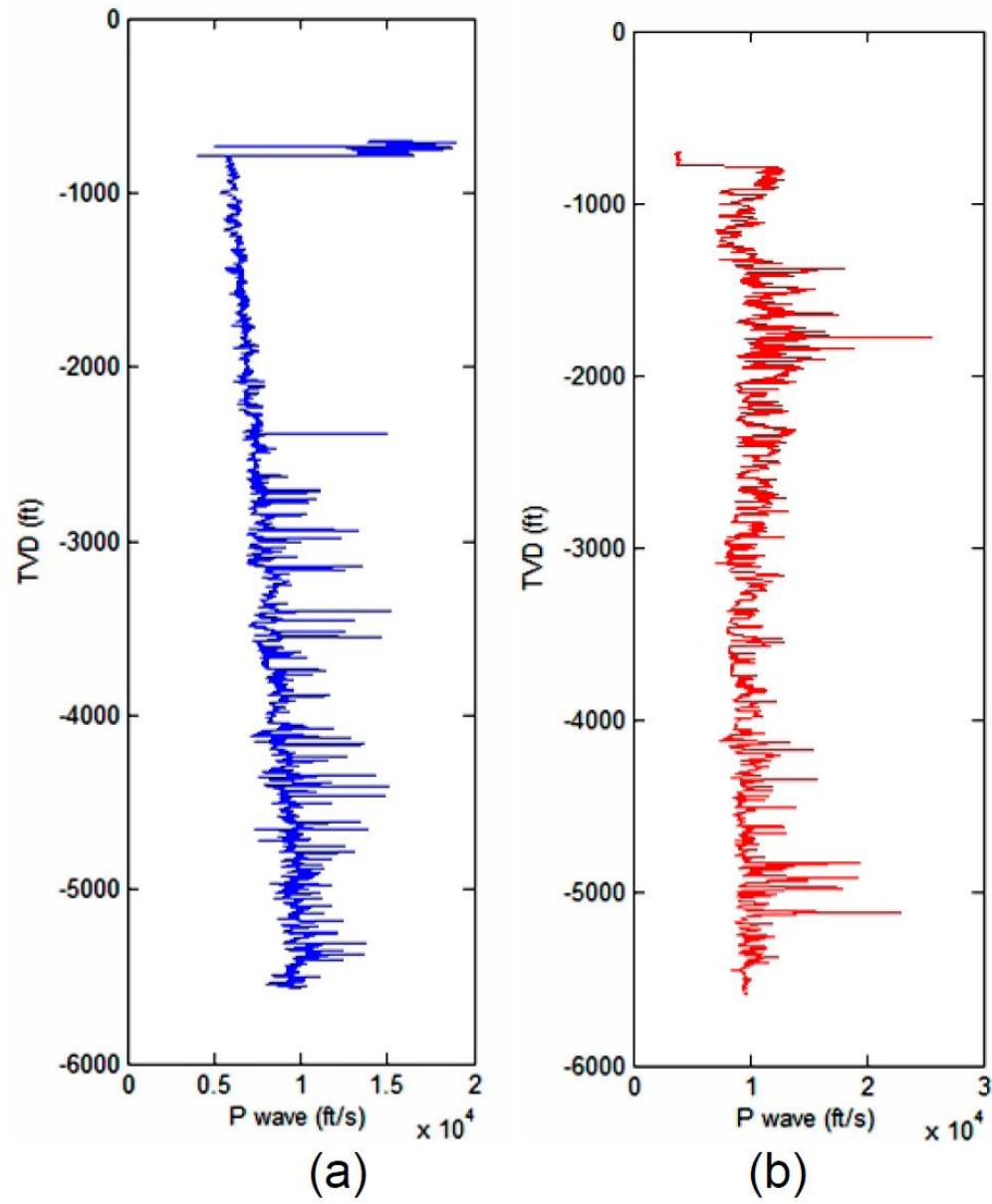
Figure 1. (a) Resistivity log and (b) Gamma ray log.

Figure 2. (a) Real V_p log and (b) Synthetic V_p by Faust's equation.
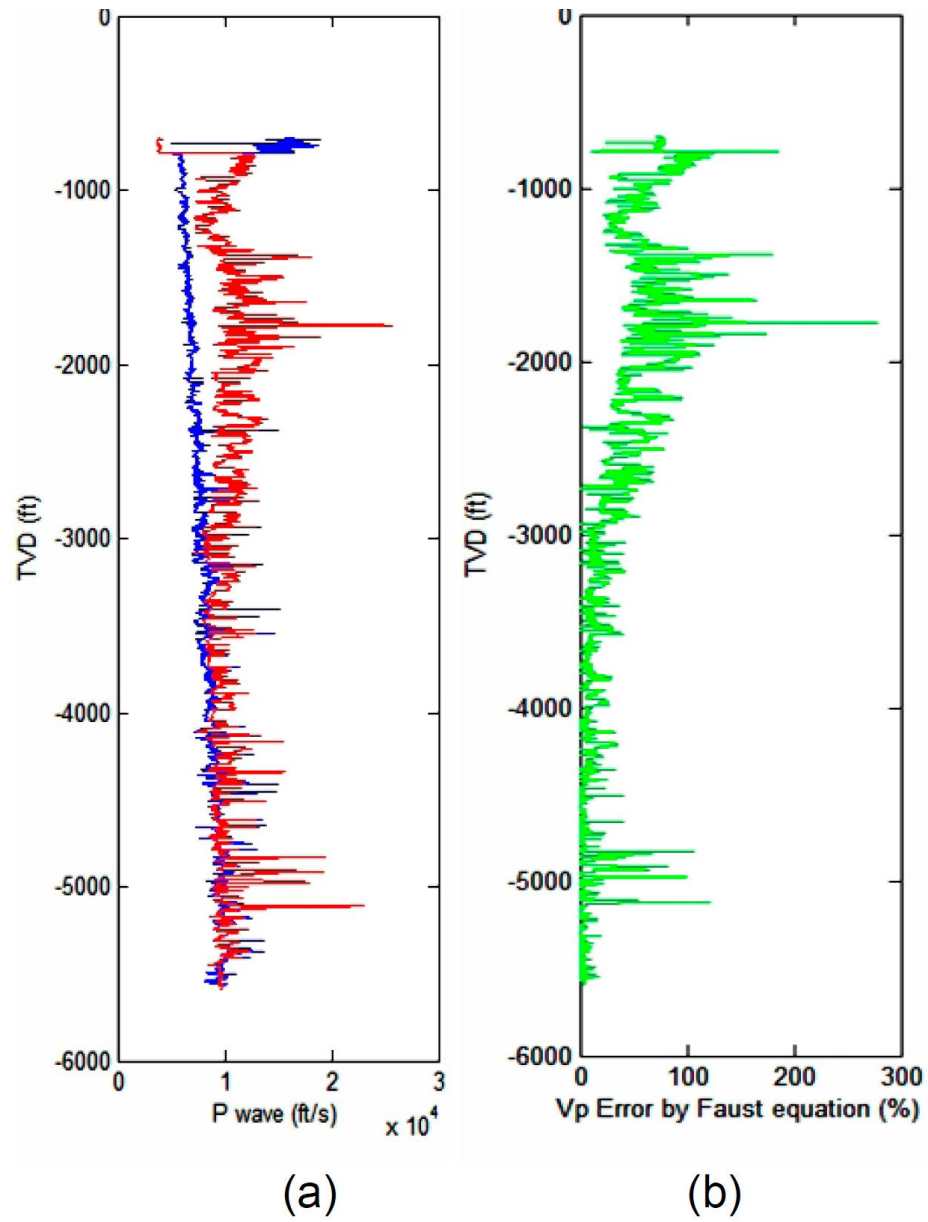
Figure 3. a) Combination of synthetic and real V_p log and (b) Error value of V_p log estimated by Faust's equation.
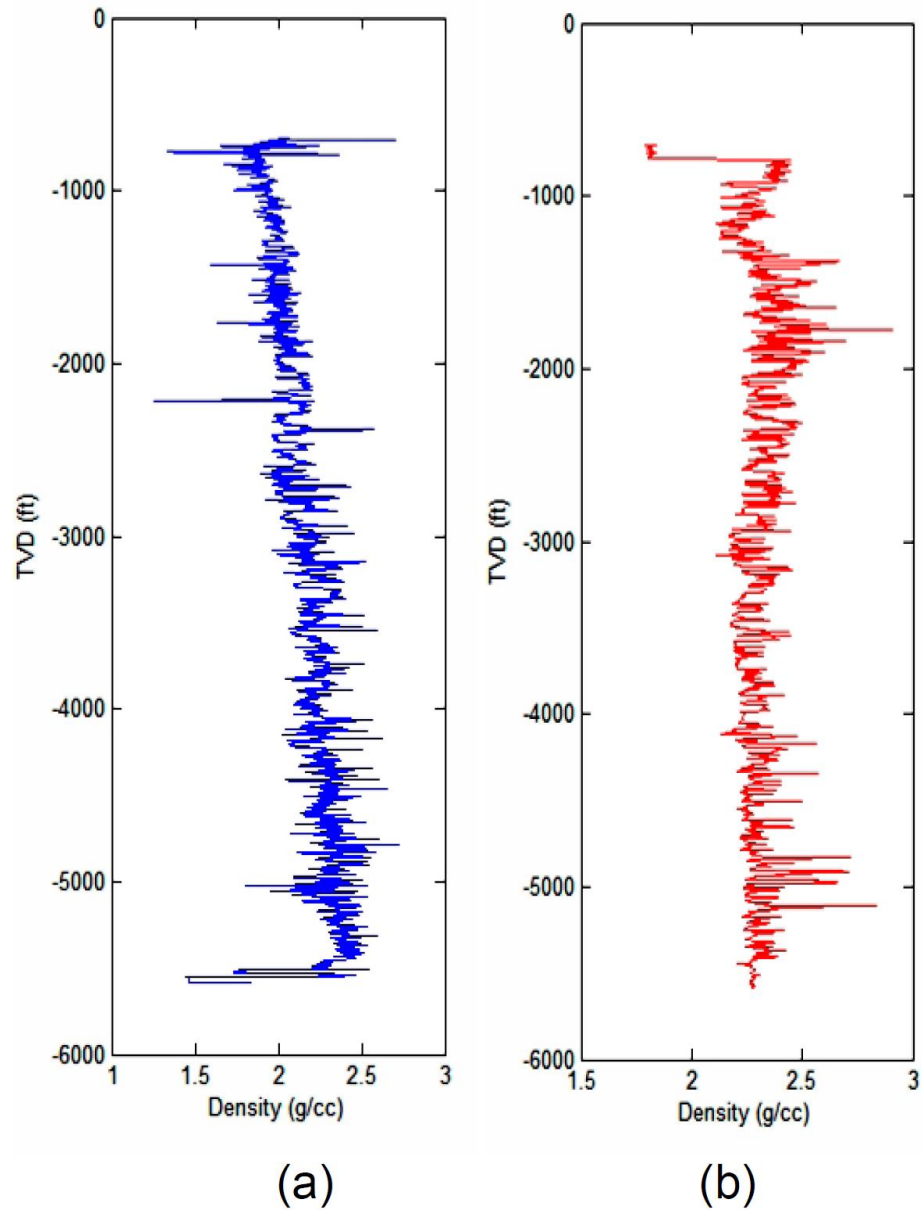
Figure 4. a) Real density log and (b) Synthetic density log estimated by Gardner's equation.

Figure 5. a) Combination of synthetic and real density log and (b) Error value of density log estimated by Gardner's equation (c) Synthetic porosity log.