International Journal of GEOMATE, March., 2021, Vol.20, Issue 79, pp. 125-131
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2021.79.j2025
Geotechnique, Construction Materials and Environment

IMPACT OF LOGGING SPEED ON SEDIMENTARY ROCK IDENTIFICATION BASED ON LONG AND SHORT DENSITY LOG

*Supandi[1]

[1]Department of Mining Engineering, Institut Teknologi Nasional Yogyakarta, Indonesia

*Corresponding Author, Received: 11 Nov. 2020, Revised: 14 Dec. 2020, Accepted: 28 Jan. 2021

ABSTRACT: Logging speed has an influence on data quality of logging result because each rock has its own characteristics. Sedimentary rocks with low mechanical properties have specific geophysical characteristics, therefore in logging activity, it is necessary to determine the optimum speed to obtain the best data quality. This research aims to evaluate optimum logging speed for sedimentary rocks to determine the logging speed that is suitable for the characteristics of sedimentary rocks. The research was conducted by logging one of the drilling holes using GDDC probe. The logging speeds used in the measurement were 3, 4 and 5 m/min. For each measurement, data values of long spaced density (LSD) and short spaced density (SSD) were obtained. The data was evaluated by statistical analysis using Friedman test. The result shows that LSD data result at logging speed of 3 m/min is different from the data at the speed of 4 and 5 m/min; while the SSD data result at logging speed of 3, 4, and 5 m/min are different from each other. A logging speed of 4-5 m/min is recommended for logging activity on clastic sedimentary rocks that have low mechanical properties.

Keywords: Long spaced density, Short spaced density, Geophysical log, Logging speed

1. INTRODUCTION

Rock density in general is the ratio between the mass and the total volume of the rock. There are five density measurements, namely: true density, apparent density, bulk density, in-place density, and particle density. True density is the mass divided by the volume not including the pores present. Precise determination of true density requires complete filling of the pore structure by a fluid of known density that does not interact with the solid. Apparent density is determined by immersing the sample in a liquid followed by measuring the volume of the liquid being displaced (pycnometer method). Bulk density is the mass of a sample divided by the volume of the sample. The in-situ density value depends on true density, particle size, size distribution, particle shape, surface water content, and degree of compactness. In-situ density should include an estimate based on a saturated sample to allow adjustment for the field water content.

Particle density is a weight of unit volume of a solid, including pores and cracks [1]. Downhole geophysicaldensity logs can be used to accurately identify various geological formations [2]. Comparison of density logs and laboratory tests of rock density in oil fields shows a strong correlation [3]. Temperature has been shown to be a significant factor in the changes of mechanical properties of fine soil [4]. Optimum porosity for cavity and groove obstacle in sedimentary rock is 22% and 19%, respectively [5]. Geotechnical characterization can be identified by using geophysical logs with the Prompt Gamma Neutron Activation Analysis (PGNAA) method [6]. Increasing logging speed will affect the quality of generated data, thus logging speed must be determined based on the characteristics of existing rocks [7]. High accuracy based on geophysical data depends on the speed used in each tool and the geophysical log with high accuracy must read up to a thin layer of the formation [8]. The optimum speed must take a mathematical approach in line with the data acquisition process so that there is no delay that can affect the quality of the data [9]. Density log with good condition of borehole can accurately measure bulk density and also predict porosity estimates [10].

Geophysical well-logging is a process of recording subsurface data using a measuring instrument inserted into a borehole, which detects radioactive signals present in each rock. According to [11], geophysical well logging is a method of measuring and recording physical properties of rock or lithology of a formation at each depth. A wireline log is a continuous recording of data from measurement in one borehole to investigate the response to variation in physical properties of rock originating from borehole drilling. Radioactivity is a process of is a process of spontaneous decomposition of certain atomic nuclei followed by the emission of alpha particles, beta particles, or gamma radiation. The rays emitted are called radioactive rays, while the substances that emit radioactive rays are called radioactive substances.

Density log is a tool that utilizes radioactive ray source to measure density of rock. According to

[12], the working principle of density log is that a radioactive source from a measuring device emits gamma rays with a certain intensity of energy through rock formation. Rocks are formed from mineral grains, and minerals are composed of atoms consisting of protons and electrons. Gamma ray particles hit the electrons in rocks. As a result of this collision, gamma ray will experience a reduction in energy (loose energy). The energy that returns after experiencing the collision will be received by a detector that is in a certain distance from the source. The intensity of reflected gamma ray depends on the density of rock formation [13]. The weaker the energy returned shows the more electrons in the rock, which means that the more dense the grains or rock-forming minerals per volume. The quantity of the energy received by the detector depends on:

1. The density of rock matrix
2. The amount of rock porosity
3. The amount of density contained in the rock pores
4. The size of borehole (borehole diameter)
5. Mud cake (mud crust)
6. The spacing of source detector (long or short)

The volume of rock investigated by density log depends on the distance between the radioactive source and the detector. For rocks that do not require high resolution, it is better to use the detector that is relatively far from the source, which is long spaced density tool (BPB manual in [11]). There are two types of density log, namely long spaced density (LSD) and short spaced density (SSD). The uses of long spaced density log and short spaced density log are as follows (Fig.1):

1. Long spaced density log is used for subsurface evaluation because it shows a density value that is close to the actual due to the small influence of the borehole wall. The source distance is ± 16 inches.
2. Short spaced density log has a vertical resolution that is high enough than long spaced density log, so this log is very suitable for measuring the thickness of subsurface layers. The source distance is ± 7 inches.

The research was conducted at Warukin Formation in South Kalimantan, which consists of sandstone, claystone, mudstone, and coal with low mechanical properties. Sandstone and claystone will experience degradation of physical and mechanical properties when they are exposed. The hardness is approximately 700 kPa with cohesion value of about 40 kPa and internal friction angle of 350°. The sandstone is composed of more than 80% of quartz minerals in fine and medium size [14]. The claystone is composed of clay-sized quartz minerals with mineral content of illite <10% and kaolinite <20%; no other clay minerals were found [15]. The groundwater level is relatively low with a depth of about 15 m from the surface.

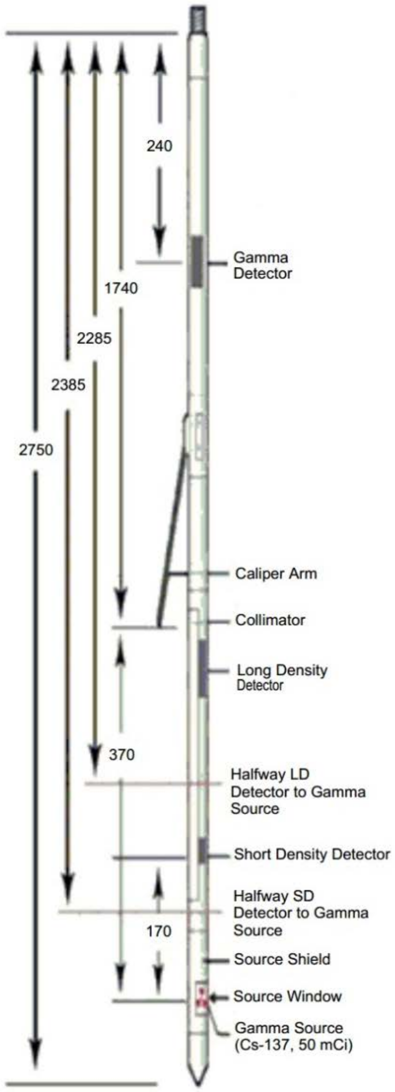

Fig.1 Short spaced density (SSD) and long spaced density (LSD) with dimension in millimeter [16].

2. MATERIA AND METHOD

Geophysical logs were obtained from drilling activity carried out on sedimentary rock with low mechanical properties. Logging activities were carried out after the drilling activity had reached the end of hole and the drilling hole had been flushed. Log measurement used the GDDC (Gamma Dual Density Caliper) type probe. The operating conditions were temperature of less than 85°C, a pressure of less than 5000 psi, hole diameter of 200 mm, and logging speed of 2-6 m/min. In general, the data collection procedure was as follows:

1. Assembling logging tools

2. Recording data, began by inserting a detector into a borehole, which is a vertical sonde, and was continued by recording data using a density logging tool with predetermined depths
3. Interpreting geophysical logging data based on the results of speed variations of the recorded data
4. Analyzing the data

This research used various logging speed to evaluate the best consistency of the data according to the lithological characteristic in the research location. By using different logging speeds, it is possible to obtain variations in numbers from both long spaced density (LSD) log and short spaced density (SSD) log. The research location was in the Warukin formation which is composed of sandstone, claystone, and coal with low hardness [14-15,17-18].

Data measurement were carried out using the same tool in the same borehole with different depths. The logging speeds used were 3 m/min, 4 m/min, and 5 m/min. The effect of logging speed on the data obtained from SSD log and LSD log was statistically tested by finding out whether there is difference in both SSD and LSD data at different logging speeds. If there is difference, it means that logging speed has an effect on the data result. The test method used Friedman test with the following hypothesis:

$H_0: \tau_3 = \tau_4 = \tau_5$ (There is no difference in the data result at logging speed of 3 m/min, 4 m/min, and 5 m/min)

$H_1: \tau_i \neq \tau_j$ (There is at least one pair of logging speeds that has different data result)

The Friedman method, in this case, worked by ranking the SSD and LSD data resulting from the three logging speeds for each depth. Through this procedure, it can be known which logging speed produces the highest (or the lowest) SSD and LSD data. Rank of the data for each logging speed were then summed and the following test statistic [19] was calculated to test the hypothesis:

$$\chi^2 = \left[\frac{12}{nk(k+1)} \sum_{j=1}^{k} {R_j}^2\right] - 3n(k+1) \quad (1)$$

$$\chi^2 = \frac{12 \sum_{j=1}^{k} R_j^2 - 3n^2 k(k+1)^2}{nk(k+1) - \frac{\sum_{i=1}^{n}\left\{\left(\sum_{j=1}^{g_i} t_{i,j}^3\right) - k\right\}}{k-1}} \quad (2)$$

where:
n = number of rows
k = number of columns
R_j = sum of ranks in jth column
$t_{i,j}$ = size of the jth tied group in the ith block
g_i = number of tied groups in the ith block

If there are no ties among logging speed in a given depth, use Eq. (1); but if there are ties among logging speed in a given depth, use Eq. (2).

The hypothesis H_0 rejected when $\chi^2 > \chi^2_{\alpha;df}$ with $df = k - 1$. Since the significance level (α) used is 5% and k equals to 3, which is logging speed of 3 m/min, 4 m/min, and 5 m/min, then $\chi^2_{0.05;2} = 5.99$ (obtained from Chi-square distribution table); so H_0 will be rejected when $\chi^2 > 5.99$. Rejected H_0 means that there is difference in the data result at different logging speed.

When H_0 is rejected, a pairwise comparison, also known as post hoc test, is required to know the detail of the difference. There are several pairwise comparison methods, one of them is Dunn's test [20]. Dunn's test works by comparing mean rank of a pair of groups.

3. RESULT AND DISCUSSION

Data of SSD log and LSD log data were recorded in CPS (counts per second) unit. The measurement results for the three logging speed groups, which are 3 m/min, 4 m/min, and 5 m/min, showed that the SSD log data was read by the measuring device from a depth of 2.3 m to 52.95 m, while the LSD log data was read at a depth of 2.2 m to 52.85 m. The data values generated from the LSD log range from 1,600 CPS to 8,700 CPS, while from the SSD log range from 9,800 CPS to 19,000 CPS (Fig.2).

SSD log and LSD log data were analyzed separately. Each of the data was ranked, then the test statistic was calculated. Mean rank of SSD log data for logging speeds of 3 m/min, 4 m/min, and 5 m/min are 2.33, 1.98, and 1.69, respectively; while for LSD log data, respectively, are 2.19, 1.93, and 1.88 (Fig.3). Rank distribution of SSD log data for logging speed of 3 m/min is relatively clustered at high ranks (the highest data values among the three logging speed groups per depth); and for logging speed of 5 m/min, the data is relatively clustered at low ranks (the lowest data values among the three logging speed groups per depth). The rank distribution of LSD log data for logging speed of 4 m/min is similar to the rank distribution for logging speed of 5 m/min.

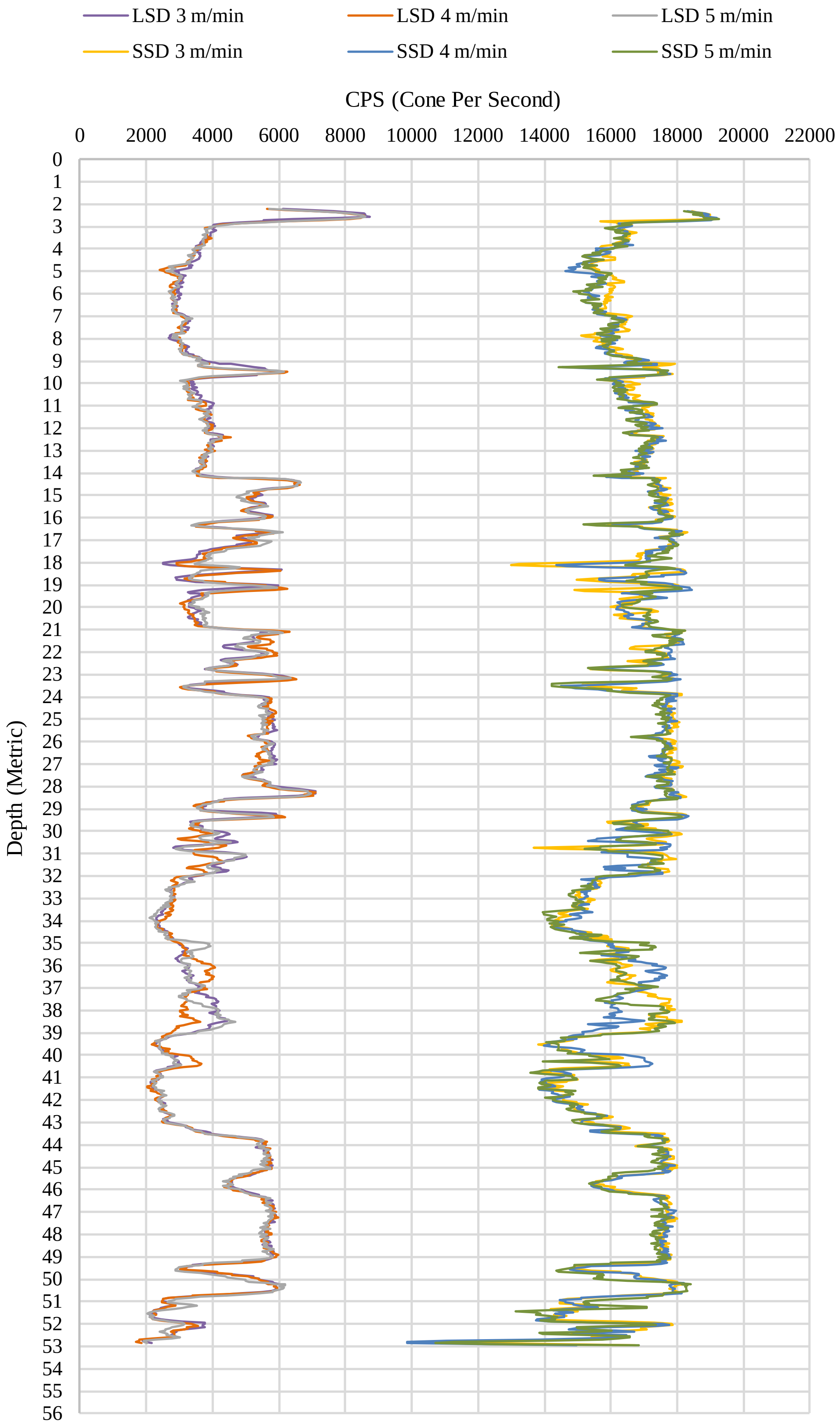

Fig.2 SSD and LSD data generated at logging speed of 3, 4, and 5 m/min

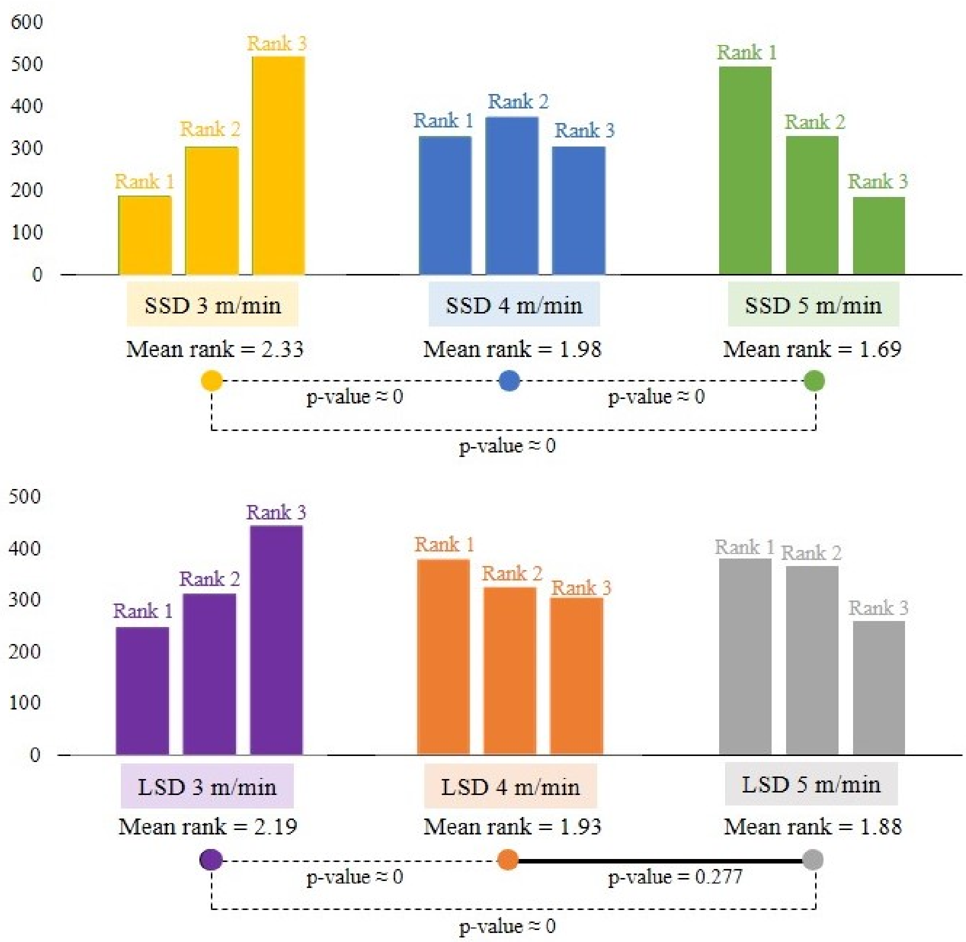

Fig.3 Rank data of SSD and LSD at logging speed of 3, 4, and 5 m/min

The Friedman test statistic (χ^2) was calculated to determine whether there is difference in each of SSD log data and LSD log data at the three logging speed groups. For SSD log data, calculated χ^2 equals to 205.74; while for LSD log data, it equals to 58.67. Both calculated χ^2 are greater than 5.99 (χ^2 from table) and thus H_0 is rejected. This means that, with a significance level of 5%, for either SSD or LSD log data, there is at least one pair of logging speeds that has different data result. To see which logging speed gives the difference, Dunn's test was performed. The test result is presented in Table 1. By seeing the mean rank difference of a pair of logging speed groups and the p-values in Table 1, we can conclude that all the logging speed groups are different from one another, except for logging speed of 4 and 5 m/min in LSD log data. It is equivalent to what the rank distribution has shown in Fig.3. This Dunn's test result is also shown in Fig.3 by lines along with the resulting p-value. The dashed line in Fig.3 shows statistically significant difference, while the thick line shows no significant difference and thus the group are the same.

Table 1 Dunn's test result

Pair	Mean rank difference	
	SSD	LSD
3 vs. 4 m/min	0.35 (0.00)	0.26 (0.00)
3 vs.5 m/min	0.64 (0.00)	0.31 (0.00)
4 vs. 5 m/min	0.29 (0.00)	0.05 (0.27)

Note: the value inside parenthesis is p-value. p-value > 0.05 means no significant difference.

4. CONCLUSION

Logging speed may affect data values resulted by log. Based on the analysis result, there is difference in the data result for either SSD or LSD log at different logging speed. The analysis result of SSD log data shows that the data values at logging speed of 3 m/min is greater than the data values at logging speed of 4 m/min, and the data values at logging speed of 4 m/min is greater than the data values at logging speed of 5 m/min. The analysis result of LSD log data shows that the data values at logging speed of 3 m/min is greater than the data values at logging speed of 4 m/min and 5 m/min, while the data values at logging speed of 4 m/min and 5 m/min are not significantly different. The results of this analysis is relevant to clastic sedimentary rocks consisting of sandstones and claystones with low mechanical properties. Previous researchers have not discussed in detail the effect of logging speed for specific sedimentary rocks with low mechanical properties. This is the novelty of this research.

5. ACKNOWLEDGMENTS

The author would like to thank the management of PT Borneo Indobara for supporting this research.

6. REFERENCES

[1] Mahajan O.P. and Walker P.L., Analytical Methods for Coal and Coal Products, 1st ed. Academic Press, 1978, pp. 125-162.

[2] McCall D.C. and Gardner J.S., Litho-density Log Applications in the Michigan and Illinois Basins, in Proc. SPWLA 23rd Annual Logging Symposium, 1982, pp. 53-73.

[3] Smith J.W., Thomas H.E. and Trudell L.G., Geologic Factors Affecting Density Log in Oil Scale, in Proc. SPWLA 9th Annual Logging Symposium, 1968, 17 p.

[4] Vahdani M., Ghazavi M. and Roustaei M., Prediction of Mechanical Properties of Frozen Soils Using Response Surface Method: An Optimization Approach. International Journal of Engineering, Vol. 33, No. 10A, 2020, pp. 1826-1841. DOI: 10.5829/IJE.2020.33.10A.02

[5] Jahangir A., Esmaili E. and Maghrebi M.F., Experimental Investigation of Porosity, Installation Angle, Thickness and Second Layer of Permeable Obstacles on Density Current. International Journal of Engineering, Vol. 33, No. 9C, 2020, pp. 1710-1720. DOI: 10.5829/IJE.2020.33.09C.03

[6] Borsaru M., Zhou B., Aizawa T., Karashima H. and Hashimoto T., Automated Lithology Prediction from PGNAA and Other Geophysical Logs. Applied Radiation and Isotopes, Vol. 64, No. 2, 2006, pp. 272-282. DOI: 10.1016/j.apradiso.2005.07.012

[7] Priest J., Frost E. and Quinn T., Speed Matters: Effects of Logging Speed on Log Resolution and Log Sampling, in Proc. SPWLA 54th Annual Logging Symposium, 2013, 16 p.

[8] Belougne V., Faivre O., Jammes L. and Whittaker S., Real Time Speed Correction of Logging Data, in Proc. SPWLA 37th Annual Logging Symposium, 1996, 14 p.

[9] Kerzner M. G., Optimized Speed Correction, in Proc. SPWLA 39th Annual Logging Symposium, 1998, 10 p.

[10] Pickel W., Kus J., Flores D., Kalaitzidis S., Christanis K., Cardott B.J., Misz-Kennan M., Rodrigues S., Hentschel A., Hamor-Vido M., Crosdale P. and Wagner N., Classification Of Liptinite – ICCP System 1994. International Journal of Coal Geology, Vol. 169, 2017, pp. 40-61. DOI: 10.1016/j.coal.2016.11.004

[11] Reeves D. R., In-situ Analysis of Coal by Borehole Logging Techniques. Canadian Mining and Metallurgy Bulletin, Vol. 64, No. 706, 1971, pp. 67-75.

[12] Harsono A., Evaluasi Formasi dan Aplikasi Log, 8th ed. Schlumberger Oilfield Services, 1997, pp. 92-93.

[13] Darmadi D., Analisis Data Well Logging untuk Rekonstruksi Lingkungan Pengendapan Batubara Daerah Pangandonan, Sumatera Selatan. Bachelor thesis, Faculty of Engineering, Universitas Lampung, Lampung, 2015.

[14] Supandi, Zakaria Z., Sukiyah E. and Sudradjat A., The Correlation of Exposure Time and Claystone Properties at The Warukin Formation Indonesia. International Journal of GEOMATE, Vol. 15, No. 52, 2018, pp. 160-167. DOI: 10.21660/2018.52.68175

[15] Supandi, Zakaria Z., Sukiyah E. and Sudradjat A., The Influence of Kaolinite-Illite Toward Mechanical Properties of Claystone. Open Geosciences, Vo.11, No. 1, 2019, pp. 440-446. DOI: 10.1515/geo-2019-0035

[16] Anonymous, Technical Specification GDDC. Surtech Indonesia, 2018.

[17] Supandi and Hartono H.G., Geomechanic Properties and Provenance Analysis of Quartz Sandstone from The Warukin Formation. International Journal of GEOMATE, Vol. 18, No. 66, 2020, pp. 140-149. DOI: 10.21660/2020.66.50081

[18] Supandi, Zakaria Z., Sukiyah E. and Sudradjat A., New Constants of Fracture Angle on Quartz Sandstone. International Journal on Advanced Science Engineering and Information Technology, Vol. 10, No. 4, 2020, pp. 1597-1603. DOI: 10.18517/ijaseit.10.4.8272

[19] Hollander M., Wolfe D.A. and Chicken E., Nonparametric Statistical Methods, 3rd ed.

Wiley, 2014, pp. 292-295.
[20] Dunn O.J., Multiple comparisons using rank sums. Technometrics, Vol. 6, No. 3, 1964, pp. 241-252. DOI: 10.2307/1266041