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Evaluation of Drill Bits Use in KRS-09 Well, Kuarsa Field Based on Well Log Data, XRD Testing and MBT From Drill Cuttings

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ABSTRACT

The use of drill bits in well drilling is very important to break and penetrate rocks. The selection of drill bits is usually done by testing drill bits from previous wells that have similar static rock mechanical parameters, but this method is time consuming and expensive because the core must be analyzed in the laboratory. As an alternative, the selection of drill bits is evaluated using logging data as an approach to calculating the Unconfined Compressive Strength (UCS) value whose accuracy is improved by integrated the brittleness index through X-Ray Diffraction (XRD) analysis and Mechanical Specific Energy (MSE) parameter to assess how efficiently drilling is performed. The obtained parameter data is then calculated for correlation using Pearson correlation. Integration of geomechanical data (UCS, BI, MSE) and mineralogy has proven to be more effective in selecting drill bits than experience-based methods. Therefore, drilling planning should consider rock strength, deformation properties, and mineral composition to improve drill bit efficiency and life.

Keywords: Brittleness Index (BI), Drill bits, Mechanical Specific Energy (MSE), Well Log data, Unconfined Compressive Strength (UCS), X-Ray Diffraction (XRD)

I. INTRODUCTION

The use of drill bits in well drilling is crucial to break and penetrate rocks, especially in formations that have a hardness level of more than medium. The selection of drill bits is based on the formation hardness category and rock mechanical parameters such as compressive strength value (Shrivastava et al., 2013). Rock mechanical parameters from how to get it is divided into static which is obtained through core testing in the laboratory, and dynamic which is obtained through the propagation velocity of P and S wave which are in the form of sonic log and/or porosity, depending on availability data.

Between static and dynamic rock mechanics there are several causes of differences such as rock heterogeneity, rock anisotropy, fluid conditions in the pores that escape/not when loaded, different strain amplitudes due to heterogeneous materials. From these causes can be eliminated by linear equations between pressure and non-elastic stiffness (Fjær, 2019 and Shen et al., 2024).

The compressive strength (UCS) is related to the mineral content of rocks where in carbonate rocks, dolomite content increases UCS, while calcite decreases it. Increasing clay also decreases UCS in carbonate rocks, but unlike sandstone, quartz decreases the compressive strength of carbonate rocks (Chen et al., 2023). The mineral content of rocks is obtained through cutting X-Ray Diffraction (XRD) analysis, because some rocks such as shale have anisotropic properties, that is shale has different mineral content when passed by sonic waves in different directions.

From the mineral data, Brittleness Index (BI) can be calculated using established equations (Perez Altamar & Marfurt, 2014). The brittleness index value is used as a measure of rock hardness and fracture strength (Kahraman & Altindag, 2004).

Drilling efficiency is known using Mechanical Specific Energy (MSE). In the Teale (1965) discovery model, it is known that bit torque is the main variable, while field data is generally in the form of surface measurements/ measurement while drilling (MWD) systems that have a high error rate, so they are only used as qualitative trend tools. In actual drilling conditions, MSE is numerically close to the formation CCS at maximum drilling efficiency (minimum MSE = rock CCS) (X. Chen et al., 2018). Furthermore Rashidi, Hareland, and Nygaard (2008) found that MSE and ROP have a linear relationship so that this method is a useful tool in direct drillbit wear analysis.

Therefore, this study will focus on develop alternative methods or improvements to the coring method to overcome limitations in terms of long time and costs more, using log data and rock characterization of compressive strength and mineral compositions. The limitations of this study are if sonic log data at certain depth interval isn't available, the resistivity log is used, and vice versa.

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The objective of this study is:

1. Determine the optimal drill bits for drilling medium to hard rock formations to increase drilling efficiency.
2. Develop alternative methods or improvements to the coring method to overcome limitations in term of long time and obtain more continuous data on the mechanical properties of rock.
3. Determine the compressive strength of the rock as a basis for selecting the appropriate type of drill bits.
4. Evaluation / analysis the effect of different mineral compositions in rock on the re response of drill bits.

II. METHODS

The methodology in this study is intended to Develop alternative methods or improvements to the coring method to overcome limitations in term of long time and obtain more continuous data on the mechanical properties of rock through several steps. Figure 1 depicts the flowchart of methodology used in this study. The methodology of this study is as follows:

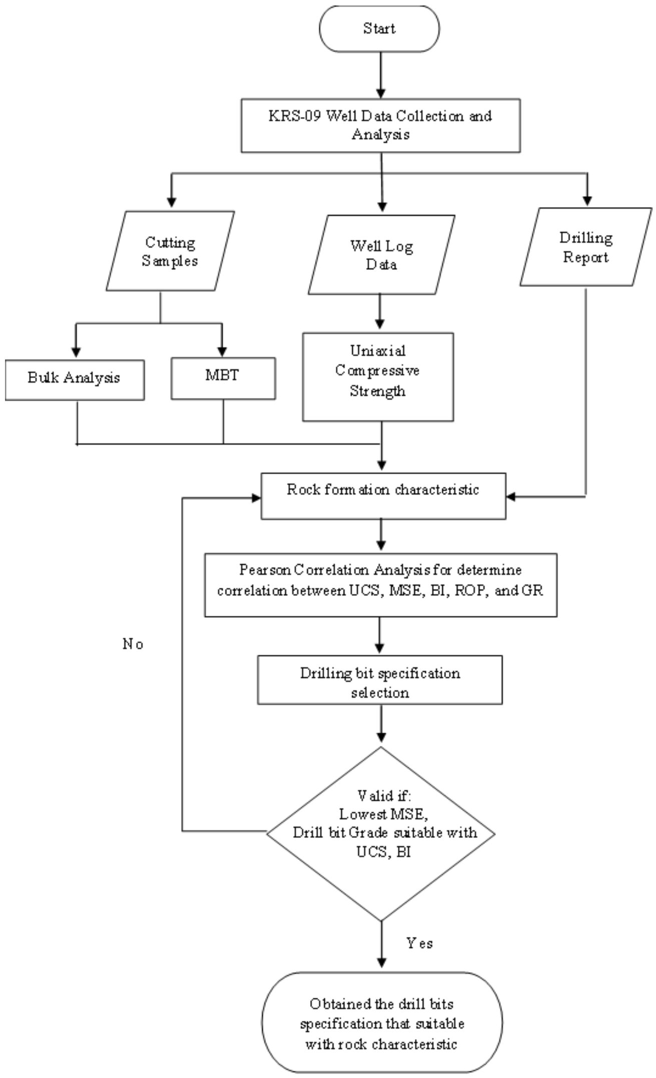

Figure 1 Flowchart Diagram Research Methods

The research began with the first step, the collection and analysis of KRS-09 Well data. The available KRS-09 Well data is in the form of well log data, drilling report data (such as RPM and WOB), and cutting samples. From the cutting samples, X-Ray Diffraction and Methylene Blue Test tests were carried out, and the Brittleness Index (BI) parameters were obtained. From the well log data, the Uniaxial Compressive Strength calculation was carried out. The results of the Bulk Analysis X-Ray Diffraction, Methylene Blue Test, Uniaxial Compressive Strength calculation, and the drilling report data, the characteristics of the formation rock were obtained. From these rock characteristics, a Pearson correlation analysis was carried out to determine the relationship between UCS, MSE, BI, ROP, and GR. After that, bits were selected based on the available specifications. The Mechanical Specific Energy (MSE) value of the bits was calculated, then an assessment was made of which drill bits had the lowest MSE value, then the drill bit grade was carried out according to the UCS and BI strength values of the rock. If it is in suitable with these parameters, the selection is valid. If there is something that does not match these parameters, it is invalid, and returns to the formation rock characteristics process. Finally, a thorough analysis is conducted to see the final result. The thesis then can be concluded and several recommendations might be made to further support the result of this study.

III. RESULTS AND DISCUSSION

KRS-09 Well, Kuarsa Field is located at East Java with the stratigraphy consisting of Lidah, Mundu, Ledok, Wonocolo, Ngrayong and Tuban Formation. The well drilling was carried out from March 3 2013 until April 18 2013. During drill the KRS-09 well, there was a challenge in selecting the right type of drill bits, which was done by testing drill bits from previous wells that had similar static rock mechanics parameters. This method requires time and cost more because the core analysis must be carried out in a laboratory. By utilizing KRS-09 Well Log combined with drilling parameters and mineralogy, it’s expected to save time and costs.

In order to support the analysis of the relationship between rock characteristics and drilling performance, several types of input data obtained from logging results, laboratory analysis, and drilling reports are used. Table 1. below summarizes the main input data used in this study, including sonic log data, porosity logs, XRD test results, gamma ray logs, and bit performance data such as ROP and MSE. These data are the basis for estimating UCS values, brittleness index, and correlation analysis between parameters

Table 1. Summary of Input Data Used

Data Component	Parameter/Description	Source	Metode/Formula Used	Note
Bit 4 & 5 UCS	UCS estimation from porosity log	Porosity log	Lashkaripour (2002), Zoback (2006)	-
Bit 7 & 8 UCS	UCS estimation from sonic log	Sonic log	Horsrud (2001), Zoback (2006), Lal (1999)	Sonic log data available
Brittleness Index	Quartz, Clay, Carbonate	XRD analysis	Jarvie (2007)	Manual calculation
MSE and ROP	Mechanical Specific Energy and Rate of Penetration	Drilling Report	API Standard MSE calculation	Drilling interval
Gamma Ray	Gamma Ray from log	Gamma Ray log	-	Indication of shale content
Mineralogical data	Mineral content	XRD analysis	-	Brittleness
Statistical Correlation	UCS, MSE, BI Pearson Correlation	Calculation	Pearson (1895)	Test interval only

3.1. Rock Mechanic Property Analysis from Sonic Log

As previously mentioned, for bits number 7 and 8, sonic log data (DT) is used, because sonic log data is available at the interval drilled with bits number 7 and 8 (top depth 6279 ft, bottom depth 7424 ft). The approach used this time is the Horsrud (2001), Zoback (2006), and Lal (1999) approach because the conditions of both the lithology and the location have conditions that match the criteria of the three approaches. Before being included in the approach, the depth is first matched and adjusted to the bit depth. The formula used is as follow:

$$UCS - Horsrud\ (2001) = 0{,}77 \times \left(\frac{304{,}8}{dt}\right)^{2{,}93} \quad (3.1)$$

$$UCS - Zoback\ (2006) = 1{,}35 \times \left(\frac{304{,}8}{dt}\right)^{2{,}6} \quad (3.2)$$

$$UCS - Lal\ (1999) = 10 \times \left(\frac{304{,}8}{dt-1}\right) \quad (3.3)$$

The UCS estimation results are presented in Table 2 below:

Table 2. UCS Estimation from Sonic Log for 7 and 8 Bit

Drillbits	Horsrud, 2001 (MPa)	Zoback, 2006 (MPa)	Lal, 1999 (MPa)
7	33,63979	38,36965	36,36773
8	45,84634	50,59004	40,6162

3.2. Rock Mechanic Property Analysis from Porosity Log

Meanwhile, for bits number 4 and 5, porosity log data (NPHI) is used because porosity log data is available at the drilling interval with bit number 4 (top depth 6279 ft, bottom depth 7424 ft) and bit 5 (top depth 6022 ft, bottom depth 7050 ft). The approaches used this time are Lashkaripour (2002), Zoback (2006), Lashkaripour & Dusseault (1993), Horsrud (2001), and Pappalardo (2015) because the conditions of both lithology and location have conditions that match the criteria of the five approaches. The formulas used is as follow:

$$UCS - Lashkaripour\ (2002) = 210{,}1^{-0{,}821 \times \phi} \quad (3.4)$$

$$UCS - Zoback\ (2006) = 0{,}286 \times \phi^{-1{,}762} \quad (3.5)$$

$$UCS - Lashkaripour\ \&\ Dusseault\ (1993) = 1{,}001 \times \phi^{-1{,}143} \quad (3.6)$$

$$UCS - Horsrud\ (2001) = 2{,}922 \times \phi^{-0{,}96} \quad (3.7)$$

$$UCS - Papplardo\ (2015) = 158 - 16{,}10\ \phi \quad (3.8)$$

Then the estimation results are presented in Table 3 below:

Table 3. UCS Estimation from Porosity Log for 4 and 5 Bit

Drillbits	Lashkaripour, 2002 (MPa)	Zoback, 2006 (MPa)	Lashkaripour & Dusseault, 1993 (MPa)	Horsrud, 2001 (MPa)	Pappalardo, 2015 (MPa)
Bit 4	3,69833E-06	0,011139	0,072398	0,253774	-207,187
Bit 5	6,73134E-05	0,012728	0,082728	0,289983	-259,293

The consistency of UCS estimation from two types of logs (sonic and porosity) strengthens the validity of the interpretation. Although there is no UCS core data available for direct validation, the obtained UCS values are still within a reasonable range for the dominant lithology of claystone, limestone, and sandstone, which is between 2000-20.000 psi. additional validation is done by comparing the UCS trend to the brittleness index and gamma ray values. However, the Pappalardo approach (2015) was not used because when used it produced a negative UCS value.

Because the UCS value based on the approach through porosity log data is considered too small, then a test is carried out using a linear regression equation using sonic UCS data with porosity log UCS data. From the linear regression equation, it is then used to calculate the corrected porosity log UCS value. The results of the linear regression are shown in Table 4:

Table 4. The Linear Regression Results

Drillbits	UCS-Zoback (2006) (MPa)	UCS-Zoback (2006) correction (MPa)
Bit 4	0,011139	17,64646
Bit 5	0,012728	17,80479

Then the UCS value of the corrected porosity log is plotted and compared with the UCS sonic log data in the scatter graph below:

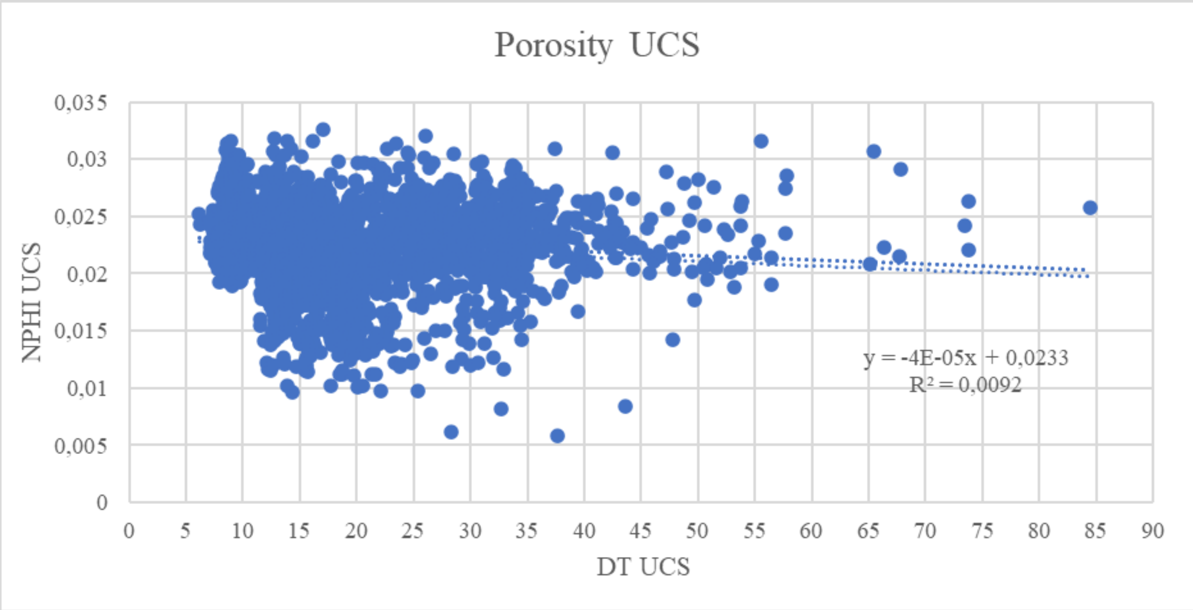

Figure 2. Porosity UCS versus Sonic UCS Scatter Plot

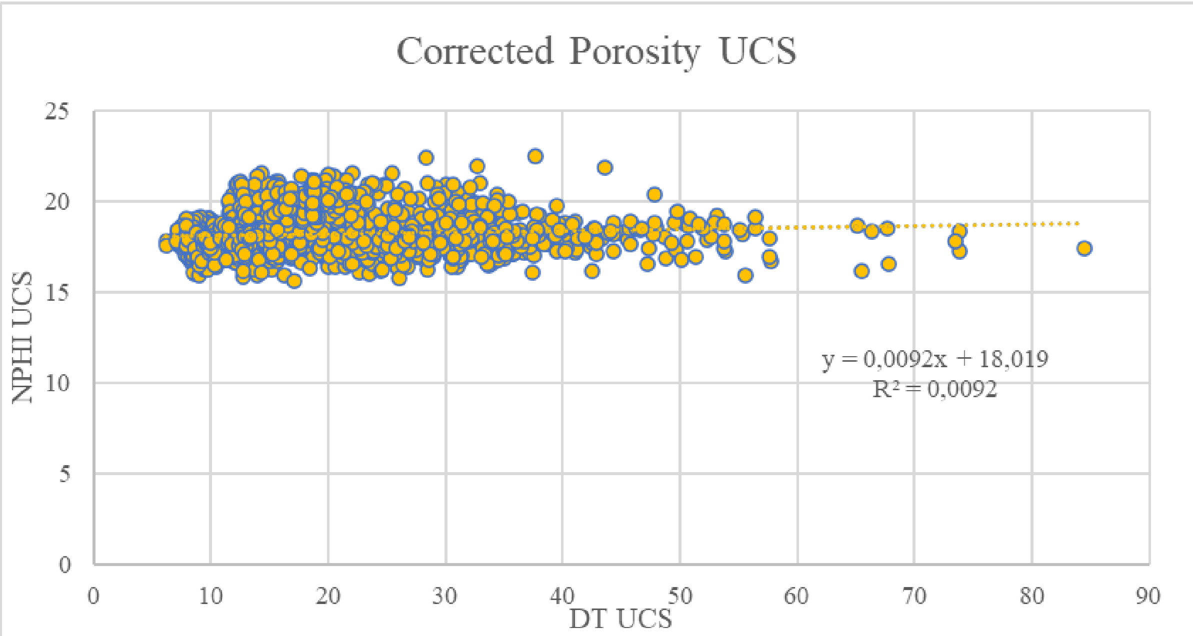

Figure 3. Corrected Porosity UCS versus Sonic UCS Scatter Plot

Based on Figure 2 and Figure 3, a comparison between the UCS value using the porosity log directly and the sonic log using a linear regression equation is seen, where in Figure 2 before the correction, a weak relationship was seen between the two variables, the sonic log UCS and the porosity log UCS which is indicated by data points spread widely without a clear pattern with a regression equation of y = -4E-05x + 0,0233 and a very small R^2 value of 0,0092. After correction with linear regression, Figure 3 shows a more structured pattern with data points that are more clustered around the regression line. The regression equation changes to y = 0,0092x + 18,019 which reflects a better relationship between the sonic log UCS and the porosity log UCS. Although the R^2 value remain the same, this correction helps to improve the consistency and interpretation of the relationship between the variables, allowing for more accurate analysis and can be used for better predictions.

3.3. Brittleness Index Analysis from X-Ray Diffraction Testing

X-Ray Diffraction testing shows variation in mineral composition throughout the drilling interval, with the three main minerals identified being quartz, clay (illite, smectite, kaolinite) and calcite. These mineral compositions affect the physical characteristics of the rock such as compressive strength, brittleness, and plasticity, which have a direct impact on drilling performance. The results of the XRD test are presented as percentage in Table 5 below:

Table 5. Mineral Percentage on Bit Interval Cutting

Mineral (Avg)	Bit 4	Bit 5	Bit 7	Bit 8
Quartz	57,319	52,817	57,554	53,525
Clay	19,327	21,113	12,871	11,417
Calcite	9,333	7,981	13,478	15,852
Feldspar	1,306	0,943	3,926	2,725
Apatite	2,658	3,137	0,793	1,329
Pyrite	3,514	3,784	3,126	2,857
Dolomite	0,581	1,687	0,000	0,822
Sillimanite	0,426	1,526	1,494	2,998
Kaliophilite	0,899	1,873	2,134	3,070
Epidote	4,636	5,139	4,624	5,404

Then, from the percentage value of minerals in each interval, referring to the equation proposed by Jarvie (2007), the percentage of quartz, clay, and calcite minerals are used to determine the Brittleness index value of the rock. The formulas used is as follow:

$$BI_{Jarvie\ (2007)} = \frac{Quartz}{Quartz+Calcite+Clay} \quad (3.9)$$

The results of which are presented in Table 6 below:

Table 6. The Brittleness Index Value at Interval Bit

	Bit 4	Bit 5	Bit 7	Bit 8
Brittleness	0,667303	0,644629	0,684466	0,660016

Then, the brittleness results for each bit are plotted into a scatter plot with the UCS value for each bit below:

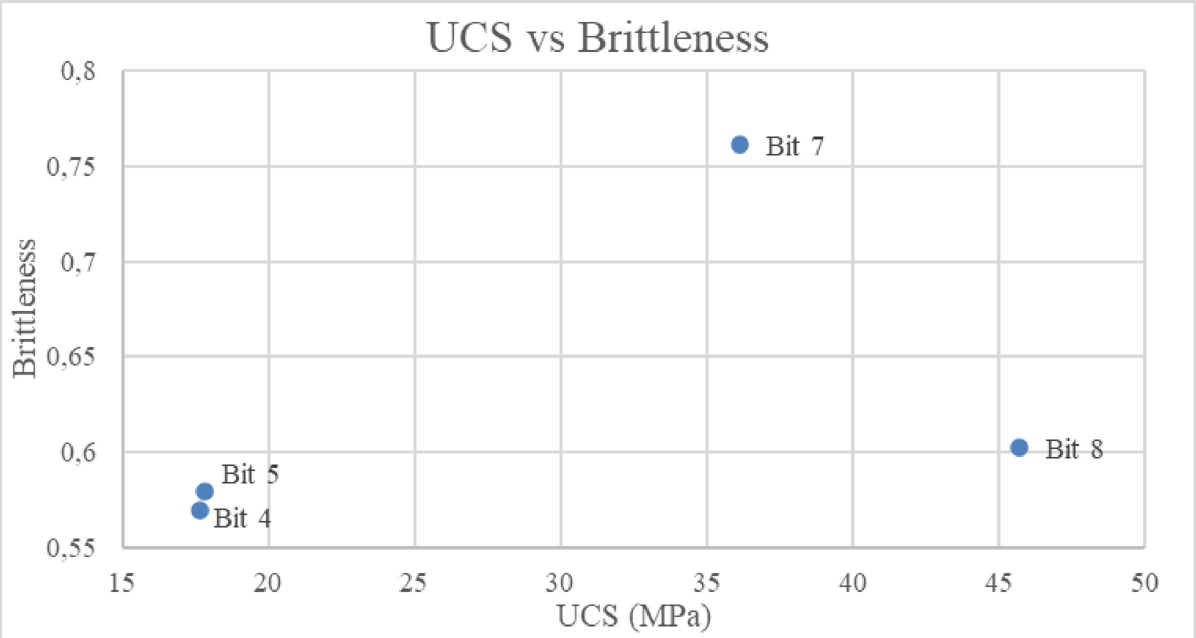

Figure 4. UCS versus Brittleness

From **Table 6**, it can be seen that each bit penetrates rocks with brittle rock characteristics, where the most brittle/fragile is at interval bit 7. Then the brittleness results of each bit are plotted into a scatter plot with the UCS value of each bit, which is displayed in the **Figure 4**, where bit 4 and bit 7 show a combination of medium UCS with high brittleness, while bit 5 and bit 8 have brittleness that decreases as UCS increases. This indicates that rock strength is not always positively correlated with brittleness properties. Strong but ductile (low brittleness) rocks still require large energy to be destroyed, as seen in bit 8.

3.4. Mechanical Specific Energy (MSE) Calculation

The Mechanical Specific Energy (MSE) value of the bit is calculated from drilling parameters including Weight on Bit (WOB), bit circumference area, Rotate Per Minute (RPM) of the bit, and bit torque to determine how efficient the drilling is. The smaller the MSE value, the more efficient the drilling is. The formulas used is as follow:

$$MSE = \frac{WOB}{area} + \frac{2 \times \pi \times RPM \times Torque}{area \times ROP} \quad (3.10)$$

The results of which are presented in Table 7 below:

Table 7. Mechanical Specific Energy on Each Bit

	Bit 4	Bit 5	Bit 7	Bit 8
MSE	1107749764,263	811347111,241	2066456823,844	838458624,678

3.5. Pearson Correlation Calculation

Finally, from all the data that has been processed into parameter data, then it is seen how the nature of the parameters is wheter they are related, less related, or in the opposite direction to the values of the parameters. The equation uses Pearson correlation below:

$$r = \frac{\Sigma(x_i - X)(y_i - Y)}{\sqrt[2]{\Sigma(x_i - X)^2 \Sigma(y_i - Y)^2}} \quad (3.11)$$

The results of which are presented in Table 8 below:

Table 8. Pearson Correlation Results

Parameter	UCS	MSE	Brittleness	ROP	GR
UCS	1,000	0,338	0,562	0,206	-0,224
MSE	0,338	1,000	0,939	0,683	0,254
Brittleness	0,562	0,939	1,000	0,310	0,226
ROP	0,206	0,683	0,310	1,000	0,395
GR	-0,224	0,254	0,226	0,395	1,000

It can be seen that MSE has a very high correlation with Brittleness (r = 0,939), indicating that an increasing in one parameter is likely to be followed by an increase in the other. In addition, brittleness also has a fairly high correlation with UCS (0,562), indicating a positive relationship between the two characteristics. ROP shows a moderate relationship with MSE (0,683), indicating that the rock cutting mechanism is quite closely related to the effectiveness of excavation. Meanwhile, the GR log value has a negative correlation with UCS (-0,224), indicating that a higher GR log value is associated with weaker rocks. From this analysis we can conclude that several parameters have strong relationship with each other, which can help understanding rocks behavior. It should be noted that certain rocks such as shale have anisotropic properties. The parameter pattern is based on P and S sonic wave measurements made in vertical wells, which measure the vertical component of elastic impedance. The horizontal component of velocity (and therefore impedance) is not measured at all. Surface seismic inversion is sensitive to the vertical component of impedance at close angles of incidence. Anisotropic effects affect reflections at larger angles if incidence.

IV. CONCLUSION

Based on the integration of UCS, mineralogy, and drilling performance data on selected bit pairs, the conclusions were obtained:

1. Integration of geomechanical data (UCS), drilling performance, and mineralogy has proven to provide a more effective quantitative approach in drillbit selection compared to conventional methods based on field experience.
2. Uniaxial Compression Strength (UCS) estimation from sonic logs is more accurate and reflects lithological variations, while porosity logs are only useful for relative distributions due to their weak correlation (r = -0,0957).
3. High quartz content (>50%) correlates with high BI and UCS values, as well as better drilling efficiency; conversely, high clay content decreases BI and increases MSE, indicating more ductile rocks and wastes drilling energy.
4. Drilling performance is strongly influenced by the combination of mechanical properties (UCS, BI) and mineralogy; hard but ductile rocks still show high MSE and low efficiency.
5. Differences in performance between identical bits confirm that non-elastic parameters such as brittleness play a major role in drilling efficiency.
6. Future drilling planning should consider rock strength, deformation properties, and mineral composition to improve operational efficiency and drillbit life.

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