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MODIFICATION OF ROCK MASS CLASSIFICATION IN THE ROCK SLOPE PLATY JOINTED ANDESITE AT SELOHARJO AREA

*Arie Noor Rakhman[1,3], Zufialdi Zakaria[1], Dicky Muslim[2], Iyan Haryanto[2], Sri Mulyaningsih[3]

[1]Post Graduate Programme of Geological Engineering, Universitas Padjadjaran, Indonesia; [2] Geological Engineering, Universitas Padjadjaran, Indonesia; [3]Mineral Technology, Institut Sains & Teknologi AKPRIND, Indonesia

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ABSTRACT: The research area is located in the Seloharjo Area, the southern hills of Opak River, Bantul Regency, Yogyakarta Special Region, Indonesia. This study explores the application of rock mass classification assessment by modifying the Q system (SQR) for rock slope stability (SMR) where the constituent lithology is platy jointed andesite. Andesite in the research area is lava haze, where currently the rock slopes are prone to rockfall since the earthquake in 2006. Correction of Q system parameters in the research area is controlled by oriented slopes and joints that were weathered into clay minerals filling the joints. Slope between 74° and 78° with strikes of the slope face between N 110° E and N 228° E. Strike direction of the planar joint plane is between N 136° E and N 238° E with an angle of dip is 20° and 26°. The presence of secondary minerals dominated by smectite and illite clay minerals. Based on the value of the RMR between 43 and 72 with the SMR value between 59.99 and 87.03, the Q value between 7.47 and 299.35, the SQR value between 84.58 and 2,564.10, the equation in the form of SMR = 7LnSQR + 30 is obtained.

Keywords: Modification, Q-system, Lava, Platy joint, SMR

1. INTRODUCTION

The research area is located at a cliff along the Imogiri-Kretek, Seloharjo area, Bantul Regency or 21 km from Yogyakarta to the south, Indonesia. The UTM coordinates of the research area is in 425,208.944 to 425,397.893 mE and from 9,116,652.795 to 9,116,892.772 mN. The location was composed of cracked volcanic rocks, where it was prone to rock mass movement. Cliffs that have the same direction as the fault line of the Middle Miocene tectonic in the Southern Mountains where the direction of the northeast generally has the potential of mass movement of rocks collapsed after the 2006 earthquake, especially on the cliff side of Opak River [1, 2]. Rockfall is potentially caused by vibrations of the earthquake waves that propagate through the weakening zones such as joints and fault [3]. Opak River is a fault line or known as Fault Opak is a major fault with the orientation of the movement of the fault block is directed northeast-southwest direction. The fault is formed from the reactivation of the normal fault during the formation of graben in the Paleogenic Period [1, 4].

Regional geological mapping shows the lithology of the hill consists of andesite lava rocks, some intrusions, and andesite breccia as part of the Nglanggran Formation. Volcanic rocks were part of the Nglanggran Formation where the rocks were Miocene-aged [5]. The outcrop of lava in the field has been intruded by andesite dike, as it was the existence of a typical group of ancient volcanoes Parangtritis – Sudimoro [6]. The Pattern of tectonic structure of tectonic product Early Miocene in the form of fault which have the direction of fracture south-southwest – north-northeast. The structure was a controller for the formation of volcanoes. The visible volcanic landscape was currently the product of tectonic lifting during the Middle Pleistocene. The Tertiary volcanic activity was polygenetic [6-8].

The behavior of rock mass to rock slope stability can be identified through the rock mass classification system by determining the classification of rock data [9]. Classification of rock data includes rock strength, rock quality designation, joint orientation and groundwater condition [9-12]. Barton, et al. in 1974 added the assessment of the joint system of rock blocks as a parameter of rock mass structure. There is also an assessment of joint roughness, type of mineral in the joint filing and active stress condition as part of rock block strength parameters [13]. Assessment of rock mass classification is influenced by the geological condition of an area [14, 15].

Rakhman and Triheriyadi [16] suggested that rock slopes in the research area were composed by platy jointed lava. Based on the RMR rock mass classification, the lava is estimated as a poor quality rock. One important factor that determines the stability of rock slopes is the style of the rock slope [17-20]. The relationship between the typical rock mass classification of lava igneous rocks is the result of comparison between the values of Rock Mass Rating system or RMR [10], Rock Mass Quality System or Q [13] and Slope Mass Rating system or SMR [11] for rock slopes. The purpose of this study was to obtain the relationship between the classifications of rock mass from the volcanic rock slopes of andesite lava.

2. METHOD

Primary data has been collected in the field at seven rock slope locations. The seven locations and coordinates of the location of rock slopes are presented in the table as follows (Table 1).

Table 1 Location coordinates for the seven rock slopes in the research area

Rock slope	mE	mN
IM-1	425,270.189	9,116,888.078
IM-2	425,284.927	9,116,861.998
IM-3	425,277.919	9,116,842.024
IM-4	425,323.450	9,116,892.772
IM-5	425,397.893	9,116,860.599
IM-6	425,208.944	9,116,712.925
IM-7	425,247.310	9,116,652.795

Field data collected from the seven rock slopes consists of morphological slope conditions, petrology, and rock structure. Slope conditions consist of slope height, dip slope and strike slope. Petrographic and X-ray diffraction analysis used to study the structure, texture, and mineral composition of the rock. The data of joint structure consists of a joint set, joint geometry, the frequency of joints per meter length (Rock Quality Designation*)*, the spacing distance between joints, joint wall surface, continuous joint, joint thickness, weathering conditions on rock-wall contacts, type of mineral in joint filling material and water inflow. Physical and mechanical properties of rocks identified in the laboratory include uniaxial compressive strength, weight unit, moisture, the degree of saturation, porosity, and void ratio. Data collected on rock slopes at IM-3 is additional data as a complement to previous research by the authors [16].

Assessment of rock mass classification begins by estimating the value of RMR. The RMR value was derived from the equation calculation as follows [10].

$$RMR = R_1 + R_2 + R_3 + R_4 + R_5 + R_6 \qquad (1)$$

where R_1 = rating of strength of intact rock
R_2 = rating of Rock Quality Designation
R_3 = rating of discontinuities spacing
R_4 = rating of discontinuities condition
R_5 = rating of groundwater condition
R_6 = rating of discontinuities orientation

The Q value was calculated by using the formula as follows [13].

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF} \qquad (2)$$

where RQD = value of Rock Quality Designation
J_n = rating of joint set number
J_r = rating of joint roughness number
J_a = rating of joint alteration number
J_w = rating of joint reduction factor
SRF = rating of joint stress reduction factor

The Q assessment was then referred to as Q_{ori}. As an adjustment of the Q value of the surface conditions, the Q value was calculated by the SRF value modification approach by Ajoodani-Namin in 1999 [21]. The SRF value modification is determined from the rating as a condition of the calculation results of the formula as follows.

$$\frac{JCS}{\gamma \times H} < 160 \rightarrow SRF = 0.35 \qquad (3)$$

$$\frac{JCS}{\gamma \times H} \geq 160 \rightarrow SRF = 0.11 \qquad (4)$$

where JCS = joint compressive strength
γ = unit weight of rock slope materials
H = height of rock slope

In this research, the Q value modified by Ajoodani-Namin was then referred to as Q_{mod}. The equation of the RMR to Q relationship from Q_{ori} and Q_{mod} values uses the approach to the RMR valuation relationship equation with the results of the predecessor research [22,23].

$$RMR = 9LnQ + 44 \qquad (5)$$

Furthermore, the RMR value was used for the determination of SMR and Q relationship equations. Based on the Romana equation of 1985, the SMR value can be estimated by using the formula as follows [11].

$$SMR = RMR + (F_1 \times F_2 \times |F_3|) + F_4 \qquad (6)$$

Where RMR was value of Rock Mass Rating, computed according to Bieniawski’s 1979 proposal; F_1 was depended on parallelism between joints and slope face strikes, F_1 = (1 - sin A)^2, where A was denoted the angle between the strikes of the slope face (α_s) and the joint (α_j); F_2

referred to joint dip angle, $F_2 = tg^2\ \beta_j$, where β_j denoted the joint dip angle; F_3 was rating of difference between the slope face (β_s) and joint dip (β_j); F4 was rating of method of excavation.

Corrected Q values and geometry calculations of rock slopes and discontinuities become the basis for assessment of Slope Quality Rating (SQR). The value of SQR from each rock slope is used to calculate the SMR [21].

According to predecessor researchers such as Hall in 1985 and Orr in 1992 mentioned that the relationship between SMR and RMR by following the linear regression equation [24-27]. The SMR assessment of the original RMR value was then referred to as SMR_{ori}. The RMR value from the relationship approach with the Q_{mod} value was then used to calculate the SMR. The estimated SMR value was then referred to as SMR_{mod}. From the relationship between the values of SMR_{ori} and SMR_{mod} using linear regression relationships obtained correlation coefficient values (r). The value of r was used to indicate the tendency of validating the relationship between the SMR values. The constant value of the SMR equation to Q becomes the unique value of the modified Q system for rock slope of the volcanic rock, especially the rock formations of Nglanggran.

3. RESULT AND DISCUSSION

The morphology of andesite lava hills in the study area has an elevation of 12.5 to 105 meters from sea level. The hills have a very steep slope between 74° and 78° with strikes of the slope face between N 110° E and N 228° E (Fig. 1). The andesite lava outcrop at the bottom is slightly decayed and the more upward the weather becomes stronger. Especially on joint wall surfaces, the physical appearance of rocks tends to be dark gray (fresh) on the inside and reddish brown on the surface. The small holes of scoria are common in platy jointed andesite lava.

The presence of secondary minerals dominated by smectite and illite clay minerals in XRD clay-oriented analysis shows that the structure of scoria and joint in rocks contributes to the weathering process. The existence of weathering minerals is also identified through specific gravity physical properties (2.65 – 2.80) and uniaxial compressive strength (18.71 MPa – 61.69 Mpa). Clay minerals are abundant, especially present as fracture fill minerals in fault line scarp (an example of observation location at IM-1). Bronto [6], Mulyaningsih and Sanyoto [28] suggested that andesite lava with these characteristics was part of the Nglanggran Formation as a product of ancient volcanoes where lava formed entered the marine zone. Based on field observations and references from previous researchers on the physical characteristics of the rock, it was interpreted that these properties were influenced by the process of rock formation as a lava haze or "laze".

The joint system encountered in the form of 2 joint sets where the joint is commonly held N46°E / 57° and N160°E / 59°. The position of the planar joint plane is strike direction between N 136° E and N 238° E with an angle of dip is 20° and 26°. Joints have joint spacing between 4 and 18 cm. General discontinuities condition is slightly rough surfaces, separation < 1 mm, irregular, undulating and highly weathered walls, sandy-clay coatings, small clay-fraction. Some of the others are slightly weathered joint walls, non-softening mineral coatings, sandy particles, clay-free disintegrated rock. A few of the others are slickenside surfaces, undulating with separation 1-5 mm, continuous, medium over-consolidation, softening clay mineral fillings (at the location of IM-1 observation). In a minor inflow of groundwater conditions with increasingly weathered discontinuities, it tends to affect the decrease in RQD values ranging from 87.81% to 43.37%. At IM-1, mylonite was found as a joint filler with a position equal to the fault plane of the normal fault, N53°E / 75° (Fig.2). This fault and its minor structure joint are interpreted as part of the fault that was formed from the reactivation of the volcanic structure during the formation of structure in the Paleogene Period.

Fig.1 Rock slope of IM-1, IM-2, and IM-3 from hill morphology in the research area (top). Rock slope of IM-4 and IM-5 in the eastern hill morphology (bottom left). The western part of the hill morphology for the location of rock slopes IM-6 and IM-7 (bottom right).

Fig. 2 Joint filled with clay minerals as mylonite at rock slopes of IM-1(left). Joint sets on platy jointed lava haze (right).

Based on field data and laboratory test results, the RMR parameter values for the seven rock slope locations can be summarized in the form of tables (table 2 and 3).

Table 2 The RMR classification and rating of parameters for rock slopes IM-1, IM-2, IM-3, and IM-4

Parameters	IM-1	IM-2	IM-3	IM-4
R_1	2	7	4	4
R_2	13	17	8	13
R_3	8	8	8	8
R_4	10	25	20	20
R_5	10	10	10	10
R_6	0	0	0	0
RMR_{basic}	43	67	50	55
RMR	43	67	50	55
Class	III	II	III	III
Description	Fair	Good	Fair	Good

On the rock slope at IM-5, IM-6 and IM-7 can be determined the RMR classification are shown in the table as follows (Table 3).

Table 3 The RMR classification and rating of parameters for rock slopes IM-5, IM-6, and IM-7

Parameters	IM-5	IM-6	IM-7
R_1	4	4	7
R_2	13	13	17
R_3	8	8	8
R_4	20	25	25
R_5	15	15	15
R_6	0	0	0
RMR_{basic}	60	65	72
RMR	60	65	72
Class	III	II	III
Description	Fair	Good	Fair

Rock mass classification for Q systems and rating of the parameters on rock slopes of IM-1, IM-2, IM-3, and IM-4 are as follows (Table 4).

Table 4 The Q system classification and rating of parameters for rock slopes IM-1, IM-2, IM-3, and IM-4

Parameters	IM-1	IM-2	IM-3	IM-4
RQD	55.78	84.42	43.37	52.49
J_n	4	4	4	4
J_r	1.5	3	2	2
J_a	8	2	3	3
J_w	1	1	1	1
SRF	2.5	2.5	2.5	2.5
Q (Q_{ori})	1.05	12.66	2.89	3.50
Class	D	B	D	D
Description	Poor	Good	Poor	Poor

Assessment of Q system parameters from rock slopes at IM-5, IM-6 and IM-7 are shown in the table as follows (Table 5).

Table 5 The Q system classification and rating of parameters for rock slopes IM-5, IM-6, and IM-7

Parameters	IM-5	IM-6	IM-7
RQD	55.78	59.18	87.81
J_n	4	4	4
J_r	2	3	3
J_a	3	2	2
J_w	1	1	1
SRF	2.5	2.5	2.5
Q (Q_{ori})	3.27	8.88	13.17
Class	D	C	B
Description	Poor	Fair	Good

The correlation between RMR and Q through the values of the parameters on the seven rock slopes can be presented as follows (Fig. 3).

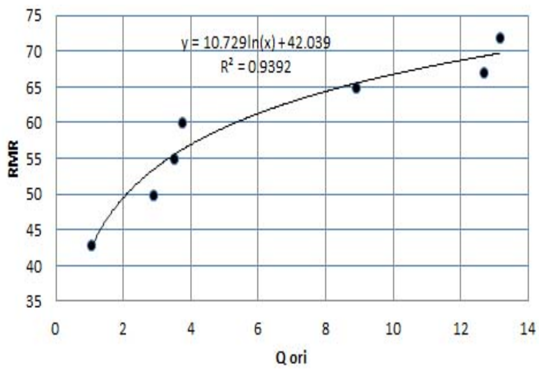

Fig. 3 Correlation relationship between RMR and Q for seven rock slopes in the research area.

According to Fig. 3, the relationship between RMR and Q (Q_{ori}) can be estimated by an equation as follows (Eq.7).

$$RMR = 11 LnQ_{ori} + 42 \quad (7)$$

In order for the Q system to be used as a rock mass classification for the application of rock slope, the Q system needs to be modified. Q system modification is done using the SRF factor formula as Ajoodani-Namin criterion (Eq. 3 and Eq.4). The Q (Q_{mod}) value obtained is the result of correction of the adjustment of initial stress conditions on the surface where its use was applied to the rock slopes of IM-1, IM-2, and IM-3 are as follows (Table 6).

Table 6 Calculation of the Q_{mod} by using SRF assessment parameters for rock slopes IM-1, IM-2, IM-3, and IM-4

Parameters	IM-1	IM-2	IM-3	IM-4
RMR	43	67	50	55
Q_{ori}	1.05	12.66	2.89	3.50
JCS (KN/m^2)	18,710	56,890	36,280	29,430
H (m)	11	13	10	9
γ (KN/m^3)	25.05	25.56	24.37	25.27
SRF	0.35	0.11	0.35	0.35
Q_{mod}	7.47	287.80	20.65	25.00

Rock mass classification for Q system modification (Q_{mod}) on rock slopes of IM-5, IM-5, and IM-6 are as follows (Table 7).

Table 7 Calculation of the Q_{mod} by using SRF assessment parameters for rock slopes IM-5, IM-6, and IM-7

Parameters	IM-5	IM-6	IM-7
RMR	60	65	72
Q_{ori}	3.27	8.88	13.17
JCS (KN/m^2)	31,390	35,320	61,690
H (m)	7	8	10
γ (KN/m^3)	25.49	24.97	25.54
SRF	0.11	0.11	0.11
Q_{mod}	84.52	201.76	299.35

The correlation between RMR and Q (Q_{mod}) results of calculations with SRF parameter determination can be presented as follows (Fig. 4).

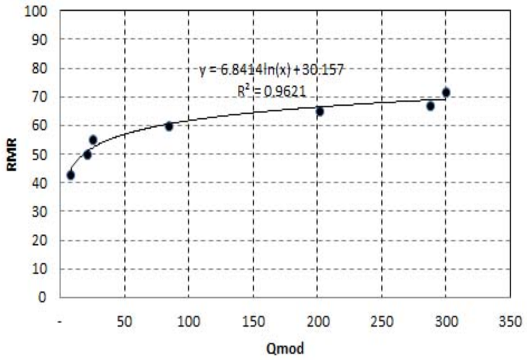

Fig. 4 Correlation relationship between RMR and Q_{mod} for seven rock slopes in the research area.

According to Fig. 4, the relationship between RMR and Q_{mod} has an R-value (R=0,9809) that is higher than the R-value of the relationship between RMR and Q_{ori} (R=0,9691). Ranasooriya and Nikraz [22], Singh and Goel [23] suggested that the high correlation coefficient of the equation (R), the equation has high validity as a Bieniawski criterion (Eq.5). The relationship between RMR and Q_{mod} can be estimated by an equation as follows (Eq. 8).

$$RMR = 7 LnQ_{mod} + 30 \quad (8)$$

The value of the corrected Q (Q_{mod}) with an increased R-value was represented by the influence of the slope height to the strength of the rock composing the rock slope as a determinant of the value of the SRF. There was a tendency that the higher the height (where the H value ranges from 7 to 13 meters) the greater the strength of the rock composing the slope (18.71 to 61.69 MPa).

Modified Q system can be applied to rock slope by approaching Q relationship with SMR through RMR. The following SMR assessment was the SMR value by rating its parameters without involving the modified Q value (SMR_{ori}). The rock mass classification value of the SMR for rock slopes IM-1, IM-2, IM-3, and IM-4 in the research area is shown in Tables 8 and 9.

Table 8 The SMR classification and parameter ratings for rock slopes IM-1, IM-2, IM-3, and IM-4

Parameters	IM-1	IM-2	IM-3	IM-4
RMR_{basic}	43	67	50	55
α_s	212	212	210	228
β_s	78	74	76	78
α_j	182	136	202	232
β_j	20	24	26	26
F_1	0.2500	0.009	0.7410	0.8654

Continued to next page

F_2	0.13	0.20	0.24	0.24
F_3	60	60	60	60
F_4	15	15	15	15
SMR_{ori}	59.99	82.01	75.58	82.35
Class	III	I	II	I
Description	Fair	Very good	Good	Very good

The SMR parameter assessment for rock slopes IM-5, IM-6, and IM-7 is shown in the table as follows (Table 9).

Table 9 The SMR classification and parameter ratings for rock slopes IM-5, IM-6, and IM-7

Parameters	IM-5	IM-6	IM-7
RMR_{basic}	60	65	72
α_s	281	160	158
β_s	78	74	78
α_j	230	238	230
β_j	20	24	26
F_1	0.0497	0.005	0.0024
F_2	0.13	0.20	0.24
F_3	60	60	60
F_4	15	15	15
SMR_{ori}	75.39	80.01	87.03
Class	II	I	I
Description	Good	Very good	Very good

The SMR_{mod} value is based on the SMR rock mass classification equation and its parameter rating (Eq.6) and the equation of the RMR relation to Q_{mod} (Eq.8) as follows.

$$SMR_{\mathrm{mod}} = 7LnQ_{\mathrm{mod}} + 30 + (F_1 \times F_2 \times |F_3|) + F_4$$

$$SMR_{\mathrm{mod}} = 7LnQ_{\mathrm{mod}} + 30 + \left(7 \times \frac{F_1 \times F_2 \times |F_3|) + F_4}{7}\right)$$

$$SMR_{\mathrm{mod}} = 7Ln\left[Q_{\mathrm{mod}} \times \exp\left(\frac{F_1 \times F_2 \times |F_3|) + F_4}{7}\right)\right] + 30 \quad (9)$$

SQR can be generated from the SMR equation [22], through the SMR equation (Eq. 9) the SQR equation is obtained as follows.

$$SQR = Q_{\mathrm{mod}} \times \exp\left(\frac{F_1 \times F_2 \times |F_3|) + F_4}{7}\right) \quad (10)$$

The SQR value of each rock slope is used to calculate the SMR with the SMR equation for the SQR value as follows.

$$SMR_{\mathrm{mod}} = 7LnSQR + 30 \quad (11)$$

The results of the calculation of the SMR on the SQR value of each rock slope are shown in Tables 10 and 11 as follows.

Table 10 The SMR_{mod} and parameter ratings for rock slopes IM-1, IM-2, IM-3, and IM-4

Parameters	IM-1	IM-2	IM-3	IM-4
Q_{mod}	7.47	287.80	20.65	25.00
F1	0.2500	0.0009	0.7410	0.8654
F2	0.13	0.20	0.24	0.24
|F3|	60	60	60	60
F4	15	15	15	15
SQR	84.58	2,456.78	797.62	1,243.96
SMR_{mod}	61.06	84.65	76.77	79.88
SMR_{ori}	59.99	82.01	75.58	82.35

Table 11 The SMR_{mod} and parameter ratings for rock slopes IM-5, IM-6, and IM-7

Parameters	IM-5	IM-6	IM-7
Q_{mod}	84.52	201.76	299.35
F1	0.0497	0.0005	0.0024
F2	0.13	0.20	0.24
|F3|	60	60	60
F4	15	15	15
SQR	762.21	1,721.16	2,564.10
SMR_{mod}	76.45	82.16	84.95
SMR_{ori}	75.39	80.01	87.03

By using the value of the calculation of SMR_{mod} and SMR_{ori}, the equation of the relationship between the two SMRs and the correlation coefficient of the equation (R) is obtained. The relationship between the two SMRs can be presented as follows.

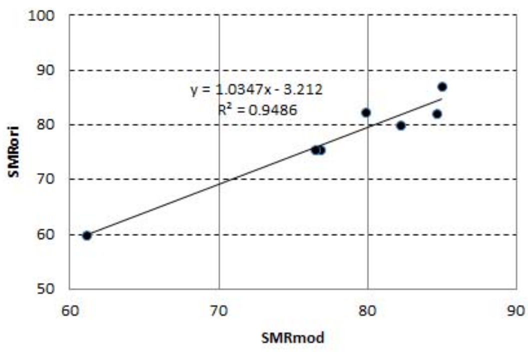

Fig. 5 Correlation relationship between SMR_{ori} and SMR_{mod} for seven rock slopes in the research area.

Based on the graph of the relationship between the SMR values in Fig. 5, it is known that the value of the correlation coefficient of the equation (R) is 0.9740. The R-value close to 1 indicates that the SMR equation resulting from SQR calculation is declared valid. This means that the value of the Q parameter modified by the relationship of the equation to the RMR can be applied to rock slope with the SMR rock mass classification assessment approach.

Correction of Q system parameters (SQR) in the research area is controlled by oriented slopes and joints that were weathered into clay minerals filling the joints. Slope between 74° and 78° with strikes of the slope face between N 110° E and N 228° E. Strike direction of the planar joint plane is between N 136° E and N 238° E with an angle of dip is 20° and 26°. The presence of secondary minerals dominated by smectite and illite clay minerals.

4. CONCLUSION

Modification of rock mass classification for rock slopes of platy jointed andesite is done by modifying the Q system (SQR). This classification has been concluded from RMR, SMR, and Q. Oriented slopes and joints that were weathered into clay minerals filling the joints are controllers of SQR values as correction of system Q parameters in the research area.

Based on the value of the RMR between 43 and 72 with the SMR value between 59.99 and 87.03, the Q value between 7.47 and 299.35, the SQR value between 84.58 and 2,564.10, the equation in the form of SMR = 7LnSQR + 30 is obtained. The application of this formula is recommended for platy jointed andesite rocks, part of the Nglanggaran Formation, especially andesite as lava haze in the research area.

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