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Lithofacies Recurrence Analysis Using Markov Chain Method in Semilir Formation, Ngoro-Oro, Gunungkidul

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ABSTRACT

The Semilir Formation located in Ngoro-Oro, Gunungkidul, has significant lithofacies diversity, reflecting dynamic depositional conditions in the past and indicating a recurring depositional pattern. The limitations of stratigraphic and geostatistical information are the main reasons for this research. This study aims to identify the characteristics of lithofacies in the Semilir Formation, Ngoro-Oro, Gunungkidul, and analyze the relationship between facies through the chi-square statistical test. In addition, the pattern of lithofacies repetition and transition is evaluated using the Markov chain method to determine the probability of lithofacies repetition and predict the stratigraphic sequence at the research location. The research was conducted on ancient rock outcrops along the Prambanan-Wonosari alternative route located in Ngoro-Oro Village, Patuk District, Gunungkidul Regency, Daerah Istimewa Yogyakarta Province by conducting stratigraphic measurements with a thickness of 78 meters using Jacob stuff then continued with geostatistical analysis using the Markov chain method. This method will provide an understanding of the prediction of lithofacies transition patterns in the research area. The research results reveal that the lithofacies at the study location consist of lithology composed of sandstone interbedded with claystone and tuff, sandstone interbedded with claystone with siltstone inserts, and sandstone interbedded with siltstone with claystone inserts. The results of the Markov chain statistical calculation of lithology or lithofacies have a non-random transition pattern.
Keyword : Semilir Formation, Stratigraphy, Lithofacies, Markov Chain

INTRODUCTION

The Semilir Formation in Gunungkidul, especially in the Ngoro-Oro, is one of the formations formed during the Tertiary period, in the form of rocks resulting from acidic volcanic eruptions, dominated by lapilli tuff and tuff, and locally, especially the lower part, mixed with clastic sediments. The lower part of this formation (lower Semilir Formation) is dominated by lapilli tuff with insertions of tuffaceous tuff and clay, tuffaceous sandstone, and pumice breccia. The rocks forming the upper part (upper Semilir Formation) are dominated by tuff with insertions of lapilli tuff, tuffaceous sandstone, and gravelly sandstone [1].

Lithofacies are a sedimentary characteristic that describes the depositional environment of a rock [2]. In the context of volcanic formations such as Semilir, lithofacies analysis can reveal transition patterns between different depositional environments, which is useful in reconstructing the geological history of an area.Stratigraphically, this formation is very interesting to study because of its diverse lithofacies composition and the indications of repeated sedimentation cycles indicating the existence of sedimentation and volcanism processes that took place on a certain time scale.

The limited stratigraphic information and the absence of research from the geostatistics side are the main reasons this research was conducted to determine the stratigraphic repetition pattern of the research area using the Markov Chain method. The Markov chain method allows the analysis of the transition probability between facies by considering the relationship between layers sequentially [3]. This approach can provide an overview of how often a particular lithofacies is followed by another lithofacies, as well as the general patterns that exist in rock stratigraphy.

Based on the Geological Map of Surakarta - Giritontro Sheet [1] the research area is included in the Southern Mountains Zone [4] with a geological structure dominated by faults trending Northeast-Southwest [5]. This study was conducted with the aim of determining the characteristics of the lithofacies of the research area, the relationship between the presence of a facies and the previous facies analyzed using the chi-square statistical test, and determining the probability that can be used to predict lithofacies repetition based on the

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stratigraphic sequence previously found at the research location, which can then be used to help predict the distribution of facies in this region, as well as providing useful information for geological exploration and resource utilization in the future [6].

RESEARCH METHOD

The research location is located at the Geological Outcrop Ngoro-oro which is administratively located on the cliff of the ancient rock outcrop of Jalan Sembada Handayani, Gembyong, Ngoro-Oro, Patuk District, Gunungkidul Regency, Special Region of Yogyakarta and is included in the Geological Map of the Surakarta and Giritontro Sheets [1]. Based on the UTM (Universal Transverse Mercator) coordinates, it is located at 448856mE and 9134394mS.

Primary and secondary data related to the research were collected. The secondary data used were in the form of regional geological data of the research area such as physiography, geomorphology, stratigraphy, and geological structure of the research area. Then, primary data collection was carried out in the form of measured stratigraphic data using Jacob's stick on an outcrop with a thickness of 78 meters.

Primary data collection began with an initial review of the research area, then continued by determining the bottom layer and the top layer of the research outcrop, then collecting measured stratigraphic data including lithological descriptions such as rock type, color, grain size texture, degree of roundness, packing and sorting in rocks, determining sedimentary structures, lithological position data, and layer thickness using Jacob's stick. After data collection, data analysis was carried out using the Markov chain method.

Markov chain analysis of lithofacies repetition is a method used to understand the transition pattern between lithofacies based on stratigraphic data. This method helps identify the possibility or probability of a lithofacies being followed by another lithofacies in a repeating sequence by utilizing previously recorded lithofacies sequence data and calculating a transition matrix that shows the frequency or opportunity for transition between lithofacies types [7][8]. Generalized coupled Markov chains have demonstrated accuracy in modeling lithofacies by integrating a variety of geological data [9]. Analysis using the Markov chain method is carried out in four stages of analysis, namely:

1) Determining the sequence of lithology based on measured stratigraphic data every 20 cm or 0.2 meters.
2) Calculate the observation transition matrix and the observation transition probability matrix to determine the repetition of lithofacies that occurs in the research area.
3) Calculating the transition probability percentage matrix and creating a Markov chain to determine the sedimentation cycle that occurs in the research area.
4) Calculate the chi-square test to determine the expected transition matrix and to determine whether the previous lithology affects the emergence of the next lithology based on the Markov chain method.

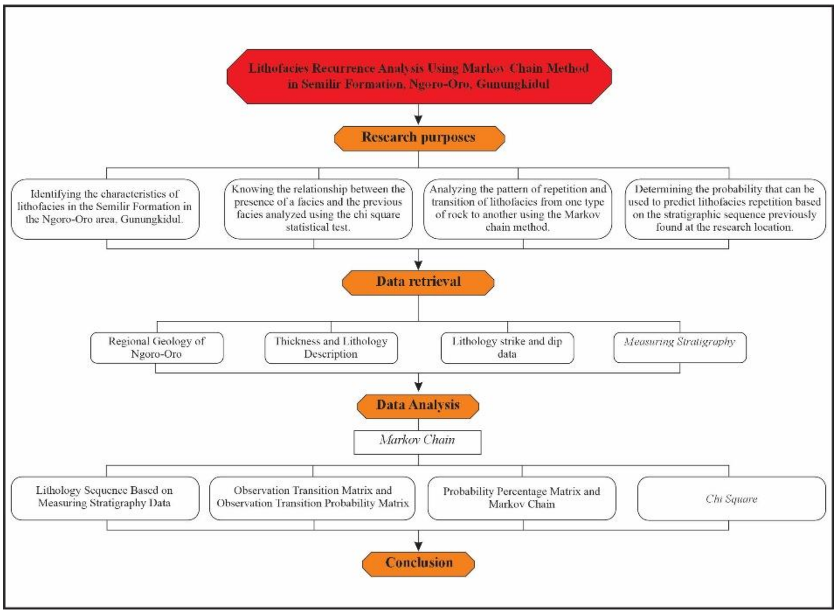
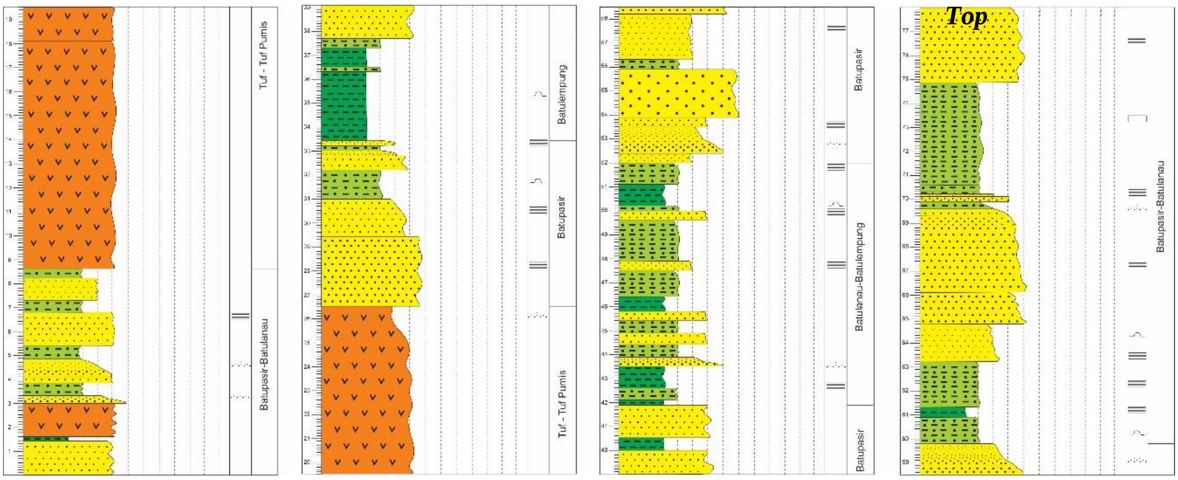


Figure 1. Flow Chart of Research Method

RESULT AND ANALYSIS

Lithological Sequence

Based on the results of data collection at the research location, a measured stratigraphic column of the Semilir Formation was obtained on the cliffs of the Ngoro-Oro area. The length of the measured stratigraphic column has a thickness of 78 meters.



Bottom

Figure2. Stratigraphic Column of Lithology Sequence from Bottom to Top in the Research Area (1st Meter is the bottom)

The measured stratigraphic column is arranged in a lithological sequence with an interval of 20 cm or 0.2 meters in the stratigraphic column of the rock layer (Figure 2.) to then be analyzed by the Observation Transition Matrix of the research area, Observation Transition Probability Matrix, Markov Chain, frequency transition probability matrix of the research area and the expected random transition matrix then obtained the pattern of occurrence between lithologies.

Bottom

1	A	A	A	A	A	A	A	B	C	C	C	C	C	C	C
2	A	D	D	D	A	A	A	A	A	D	D	D	A	A	A
3	A	A	A	A	D	D	A	A	A	A	A	D	D	C	C
4	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
5	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
6	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
7	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
8	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
9	C	C	C	C	C	C	C	C	C	C	C	C	C	A	A
10	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
11	A	A	A	A	A	D	D	D	D	D	D	A	A	A	A
12	D	A	B	B	B	B	B	B	B	B	B	B	B	B	B
13	B	B	D	B	B	B	D	D	A	A	A	A	A	A	A
14	A	A	A	A	A	B	B	B	A	A	A	A	A	A	A
15	B	D	D	B	B	B	B	A	A	D	D	D	A	A	D
16	D	D	A	A	B	B	B	D	D	D	D	D	D	A	A
17	D	D	D	D	D	D	D	D	A	A	D	B	B	B	B
18	D	D	D	D	D	A	A	A	A	A	A	A	A	A	A
19	A	A	A	A	A	A	A	A	A	A	D	D	A	A	A
20	A	A	A	A	A	A	A	A	A	A	A	A	A	A	D
21	D	D	D	D	B	B	D	D	D	D	D	D	D	D	D
22	D	A	A	A	A	A	A	A	A	A	A	A	A	A	A
23	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
24	A	A	A	D	A	A	D	D	D	D	D	D	D	D	D
25	D	D	D	D	D	D	D	D	D	D	D	D	D	D	A
26	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

Top

Description :

- A : Sandstone
- B : Claystone
- C : Tuf
- D : Siltstone

Figure 3. Lithological Composition of Research Area

Observation Transition Matrix and Observation Transition Probability Matrix

Based on the stratigraphic sequence above, it can be arranged into a matrix that shows the numbers or probability values for the occurrence of each lithology.

Table 1. Observation Transition Matrix (Left) and Observation Transition Probability Matrix (Right)

	A	B	C	D	Total
A	149	5	0	14	168
B	2	27	1	6	36
C	2	0	95	0	97
D	15	4	1	69	89
Total Coloumn	168	36	97	89	**390**

	A	B	C	D	Total
A	0.887	0.030	0	0.083	1
B	0.056	0.750	0.028	0.167	1
C	0.021	0	0.979	0	1
D	0.169	0.045	0.011	0.775	1
Total	1	1	1	1	4

Based on the transition probability matrix, observations can show the probability value of the emergence of lithology with the previous lithology (Table 1. Right). This probability value can later be used as a prediction of the emergence of the next lithology, based on the largest probability value. Based on the values above, it can be seen that the emergence of lithology in the next 0.2 meters is: Sandstone to Sandstone (0.887), Mudstone to Mudstone (0.750), Tuff to Tuff (0.979), Siltstone to Siltstone (0.775).

Markov Chains

The probability values above, arranged in the form of a diagram of interconnected shapes, are called Markov chains (Figure 4.). The diagram data is then used to determine patterns or cycles.

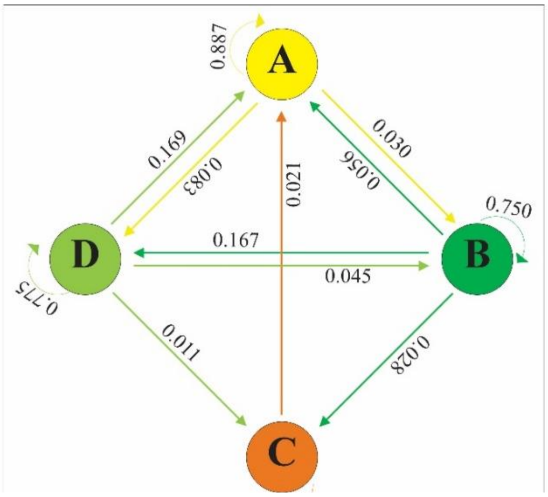


Figure 4. Markov Chain Research Area

From the results of the Markov chain analysis, four rock cycles were found, namely;

1. A (Sandstone) – B (Mudstone) – C (Tuff) – A (Sandstone)
2. A (Sandstone) – B (Mudstone) – D (Silstone) – A (Sandstone)
3. A (Sandstone) – D (Silstone) – C (Tuff) – A (Sandstone)
4. A (Sandstone) – D (Silstone) – B (Mudstone) – A (Sandstone)

3.1 Frequency Transition Probability Matrix

This frequency transition probability matrix states the expected value of each lithology and distributes it evenly at each probability by converting the probability matrix into the expected form or by multiplying the frequency transition probability matrix and the definite probability vector (Table 2.) then the expected random transition matrix is obtained (Table 3.)

Table 2. The Definite Probability Vector

A	168/390	0.43
B	36/390	0.09
C	97/390	0.24
D	89/390	0.22

Table 3. Frequency Transition Probability Matrix of the Study Area (Left) and Expected Random Transition Matrix (Right)

	A	B	C	D
A	0.43	0.09	0.24	0.22
B	0.43	0.09	0.24	0.22
C	0.43	0.09	0.24	0.22
D	0.43	0.09	0.24	0.22

x 168
x 36
x 97
x 89

	A	B	C	D
A	72.24	168.00	40.32	36.96
B	15.48	36.00	8.64	7.92
C	41.71	97.00	23.28	21.34
D	38.27	89.00	21.36	19.58

3.2 Chi Square Table Calculation

Then the observation transition frequency matrix and a random expected transition frequency matrix are tested using chi-square to determine whether the hypothesis is accepted or rejected (HI) or (HO) [3], with:

- HO = that the data comes from a random transition population, the probability of the lithology sequence is independent of the previous lithology.
- HI = that the data comes from a non-random transition population, the probability of the previous lithology sequence.

The Chi-Square test is carried out with the following calculations:

$$X^2 = \sum_{j=1}^{k} \frac{(o_j - E_j)^2}{E_j}$$

Previously, calculations were carried out on the independent variables to be included in the Chi-Square table using the calculation formula degree of freedom (V):

V = (many lithologies – 1)^2
= $(4 – 1)^2$
= $(3)^2$
= 9

Based on the independent variable data and level of significance then entered into the Chi-square distribution table, the accuracy level value obtained is 5% = alpha = 0.05, so the critical value/chi-square from the table is $X^2_{0.05,9}$ = 16.92. The table calculation value and chi-square distribution value are 932.074 > 16.92. So the HI component is accepted, which means that there is a significance that the emergence of a lithology in a broad sense depends on the previous lithology, and the lithological arrangement in the measured stratigraphy above is a patterned or non-random transition.

CONCLUSIONS

The conclusions of this study include:

1. The Semilir Formation on the Ngoro-Oro cliff, Gunungkidul, is part of a volcanic deposit formed in the Early to Middle Miocene. This formation has diverse lithofacies characteristics, reflecting the deposition process influenced by volcanic activity and shallow marine environments. This is evidenced by the presence of lithofacies such as sandstone interspersed with mudstone and tuff, sandstone interspersed with mudstone with siltstone inserts, and sandstone interspersed with siltstone and mudstone inserts. It has a texture of coarse sand to clay grain size, with good sorting and closed packing, subangular - rounded grain shape. The structures that develop in the lithofacies of the research area include layering structures, graded bedding in sandstone and siltstone, lamination structures, and also convolute structures in mudstone and siltstone.
2. The presence of a facies is highly dependent on the previous facies, where the facies arrangement has a non-random transition pattern. This is shown by the chi-square test with a calculated X^2 value (932.074)>X^2 table (16.92).
3. The facies sequence in the measured stratigraphy of the Semilir Formation in the research area shows four facies cycles, including:
    - Cycle 1: A (Sandstone) - B (Mudstone) - C (Tuff) - A (Sandstone)
    - Cycle 2: A (Sandstone) - B (Mudstone) - D (Siltstone) - A (Sandstone)
    - Cycle 3: A (Sandstone) - D (Mudstone) - C (Tuff) - A (Sandstone)
    - Cycle 4: A (Sandstone) - D (Mudstone) - B (Mudstone) - A (Sandstone)

4. The Markov chain method can perform facies repetition analysis, namely by looking at the transition probability matrix that can predict the presence of facies that will appear next according to the data to be known which is predicted by the presence of previous facies.
5. The prediction of lithology that will appear in every 0.2 meters then based on the largest percentage value with the smallest percentage value of 75% - the largest value of 97.94% is:
   - Sandstone – Sandstone = 88.69%
   - Mudstone - Mudstone = 75%
   - Tuff – Tuff = 97.94%
   - Siltstone - Siltstone = 77.53%

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