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RESEARCH ARTICLE

Correlation Between Fracture Azimuth, Surface Lineaments and Regional Tectonics: A case study from Belik District, Central Java, Indonesia

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Abstract

Two major strike-slip faults with northeast-southwest and northwest-southeast orientation have shifted the southern Central Java, including Belik District. Consequently, many smaller faults that have the same direction as the major faults and west-east direction folding systems were emerged. The orientation of these geologic structures could be observed from morphological features such as ridge and river. A quantitative approach was carried out to unravel the impacts of those geologic structures on the geomorphology of the study area, which is located between Slamet Mountain and Sindoro Mountain, Central Java province. The method used in this research was the structural geology analysis, including the interpretation of ridge and river lineament, the distribution of fractures, and statistical analysis. The research location is divided into four different segments based on its lineament and morphology. The lineament that has similar characteristics was tested using normality test of Kolmogorov-Smirnov. The Spearman test was used to obtain the correlation between surface lineament and fracture azimuth. All fracture azimuth, ridges and rivers tend to have northwest-southeast and northeast-southwest direction. These results show similar direction with strike-slip regional structural pattern. The statistical calculation and field observation indicate the influence of external factor on the change of the study area's landform.

Keywords: Fracture Azimuth, Lineament, Spearman, Belik

1. Introduction

The morphology of Central Java tends to have indentation. It is interpreted as the cause of major right and left lateral faults movement in that area (Satyana, 2005, 2006, 2009). It is also considered to be intensively affected by tectonics (Widagdo, et al, 2018). On the other hand, the condition of the outcrop is sometimes highly affected by weathering and erosion which make the tectonic features difficult to be observed.

The research location is situated between 109° 20' 4" - 109° 25' 42" East Longitude and 7° 5' 52" – 7° 13' 45" South Latitude, which is in the Central Java Province (Fig. 1). It is bordered by Purbalingga district on the south, Paninggaran on the east side, and Mount Slamet at the west side. Djuri et al. (1996) divided the stratigraphy of the study area from the youngest to the oldest into Late Pliocene Lava of Mount Slamet, Early Miocene of Rambatan Formation, and Middle to Late Miocene of Halang Formation. He stated that the Rambatan Formation consist of shale and marl alternates with light grey calcareous sandstone, while the Halang Formation have interlaminated sandstone and shale. The Central Java Province was influenced by wrench fault systems from Late Cretaceous to Paleogene, where it cut each other with left-lateral fault from northeast to southwest in Muria-Kebumen and right-lateral fault from northwest-southeast in Cilacap-Pamanukan (Satyana, 2005).

According to fault kinematic ellipsoid, the Muria-Kebumen and Cilacap-Pamanukan faults may provoke other strike-slip fault and foldings around the research area (McClay, K. R., 1991). Most folds between these two strike-slip faults have west-east direction. The lineament from Mount Slamet, Sindoro, Sumbing and Merbabu also showed the same direction with the folding (Pacey, et al, 2013).

The geologic structures can be observed with several different techniques including the direct observation in the field and laboratorial analysis and interpretation. The landscape morphology can be affected by endogenic process such as plate tectonic deformation or local geological structure. The structural geology evidence in a tropical country like Indonesia, is difficult to observe because of the high weathering rate (BNPB, 2010). Hence, laboratorial analysis and interpretation become crucial in the identification of the deformation process.

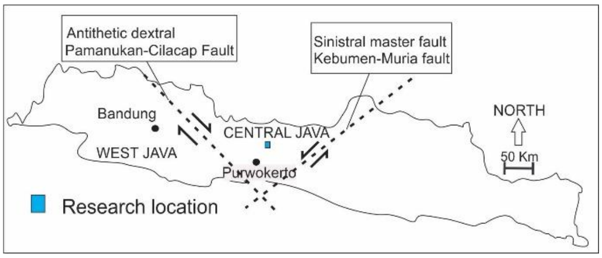

Fig. 1. Map showing the research location. The strike-slip fault cut each other in the opposite slip and trend. Modified from Satyana (2005).

We propose a combination approach, employing field acquisition and statistical analysis to study geologic structures. A Combination of these methods may increase the chance of having a better result and eliminate the uncertainty. Many successful cases have applied statistics to determine the landscape morphology evolution related with tectonics (Zadeh, et al, 2013; Vannametee *et al.*, 2014; Yudhicara, et al, 2017).

This research employs the bivariate analysis to evaluate the relationship between the fracture azimuth and the surface lineament direction. This method was chosen because of its efficiency and effectiveness to decipher the main factors that affect their development. This statistical analysis must be supported by other geological evidence in order to minimize or eliminate the error and misinterpretation.

The landscape morphology in Central Java Province tend to emerge by following the folding direction, which shows the west-east direction parallel to the folding direction. This research aims to unravel the influence of tectonics process on the formed landscape morphology and to determine which processes were more dominant compare to other geological processes.

1.1 Regional Geology

Tectonic pattern from Neogene Central Java sub basin on the northern part is a part of back-arc basin. It is formed between magmatic arc on the south (Southern Java) and the Sundaland on the north as a result of subduction between Eurasia and Indo-Australian plate.

The research area which is located in Besuki Majenang High is part of North Serayu Mountain Zone. The mountainous zone extends from west to east with the width ranging from 30 to 50 kilometers (van Bemmelen, 1949)

Situmorang et al. (1976) postulated the faulting mechanism in Java based on Riedel shear concept. Furthermore, he explained it was resulted from the collision between Eurasia and Indo-Australia plate in the Middle Cretaceous and then formed specific fault and fold pattern. Kusumayudha (1994) explained that the meridional fracture system or west to east structural orientation was affected by the compressional force from North to South (N 350^0 E). The wrench faults which were resulted on the left and right of the folding system lead to 45^0 to its compressional force. Hence, Java is divided into three blocks. The first one is positioned higher than the second and third block. Each of blocks is bordered by a couple of strike-slip fault with northwest-southeast direction between the first and the second and northeast-southwest direction between the first and the third one. All the structural from the main compressional force are categorized as a R1 and R2 system in Riedel shear model.

The North Serayu Mountain experienced three episodes of tectonics activity: (1) Miocene to Pliocene, (2) Pliocene to Pleistocene, and (3) Holocene (van Bemmelen, 1949; N. Ratman and G. Robinson,1996).

2. Methodology

This research attempted to support field observation with statistical analysis. Basic geological mapping was first carried out to check the lithology and structural geology evidence. These parameters then used to help the statistic calculation.

The research area was divided into several segments based on its morphology before the lineament was drawn. It was conducted by manual interpretation and aimed to have precise lineament trend that fit with its group, so it can represent the direction of actual alignment.

The lineament from ridge and river were calculated thoroughly. They were resulted from the topographic map and the satellite imagery. To better signify the intensity the length of lineaments is put into consideration in statistical calculation using weighting method. The result then compared with fracture measurements in the field to find out the correlation.

The fracture azimuth and lineament were compared based on its segments. For example, we compare the fracture from segment 1 to ridge and river in the same segment and others. Then we considered to calibrate the lineament with the main regional tectonics force in each segment.

Before each data compared to each other, all lineaments and fractures data were tested whether the data distribution has a normal trend or not using Kolmogorov-Smirnov test.

We use bivariate analysis to test correlation between fracture and lineament. Pearson test was used when data distribution is normal, while Spearman test was used when data couldn't be presented in normal distribution. R value is expressing magnitude of the correlation, while p value is expressing level of significance.

The statistical results were managed using SPSS software (Statistical Product for Social Science) © version 25.0.

The result was interpreted by combining the geological condition (such as geomorphology, lithology, and drainage pattern) with the statistical calculation. A good match between those parameters lead to a better understanding of the endogenic and exogenic processes in the past.

2.1 Data Availability

The lithology, the morphometry, and the fracture azimuth were acquired through field mapping. The lithology distribution has been confirmed with 33 macroscopic observation sites and 10 petrographic analysis (Fig.2). The morphometry was obtained using slope analysis (Van Zuidam, 1985) (Eqn. 1) and reconfirmed by field visit. More than four hundred of fracture azimuth were measured to determine its main direction.

$$s = \frac{(n-1).Cl}{d \times Sp} \times 100\% \qquad (1)$$

Where:

s : slope (%)
n : the number of contours cutting by a line
Cl : contour interval (meters)
d : the distance between the highest and the lowest contour (meters)
Sp : scale on the map

The drainage pattern was obtained through the studio analysis and combined with the calculation of river order from Strahler (1952). The first order which crosses into each other result in the second order, and if the first order runs into the second one, it remains the second order. The river order was conducted to analyze the river stages, whether it was young or old enough to be influenced by a geological process.

The lineament data were obtained from ridge and river using satellite imagery and topography map, respectively. We used channel 4, 5, and 7 in this satellite imagery to see the lineament trend and the drainage pattern, and successfully gained more than hundreds of lineaments. These data were then used to reconfirm the field data.

3. Results

3.1. Lithology

There are four lithology in the research location that can be simply distinguished by their texture and composition (Fig.2). More than 15 % lithology in the research area is covered by Andesitic lava flow from Slamet Mountain. The research area is also dominated by 30 % of Feldspathic Wacke Sandstone from Halang Formation and 50 % of shale from Rambatan Formation. Some Diorite intrusion was covered only 5 % on the western part of the research area.

It can be concluded from field observation that the Andesitic lava from Mount Slamet always covers the lowest part of the research area with 0 – 7 % of slope, filled in the nearby valleys and rivers. It is dark or black in color and has a porphyritic texture and vesicular structure. Besides, the Feldspathic Wacke Sandstone usually lies on the higher ground between 200 – 1,150 meters with 10 – 20 % of slope which has the interlaminated sandstone and mudstone characteristic. Most of the sandstone has a stiff rock strength. It proved by the hammer when was used to take the sample which brought out fire sparks. The shale of Rambatan Formation is overlapped with the sandstone from Halang Formation in between 100 – 850 meters. And the Diorite intrusion has located on the 650 – 1,000 meters elevation with 20 – 50 % of slope.

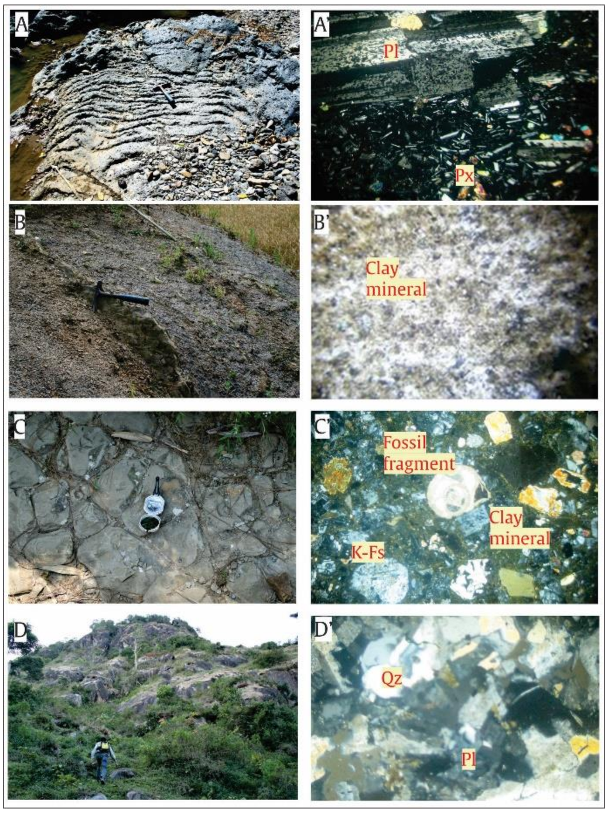

Fig. 2. Field photographs (left) and photomicrographs (right) of representative samples from research location. All photomicrographs originated from the outcrop on the left and were taken using x-nicol. (A-A') Andesitic-basalt lava flow from Mt. Slamet; (B-B') Shale from Rambatan Fm.; (C-C') Sandstone from Halang Fm.; and (D-D') Granodiorite intrusion. (K-Fs=K-Feldspar; Pl=Plagioclase; Px=Pyroxen; Qz=Quartz)

3.2. Morphology

The elevation of the research area varies from 100 m to 1,000 m above sea level. The topography is grouped into five slope classes, namely flat (0 % - 1.8 %), slightly sloping (3.6 % – 5.4 %), sloping (7.1 % - 14 %), slightly steep (16 % - 20 %), and steep (16 % - 41 %). The sloping topography is covering 55 %, and the the slightly steep slope covering 30 % of northeast and south part of research area in, and the other classes are scattered evenly.

Most slopes are consisted of Rambatan and Halang Formation, except for flat and steep slope which consisted of andesitic lava and granodiorite intrusion, respectively. The valley is categorized as dull to sharp v-shape and dull u-shape.

According to the elevation and slope classification of van Zuidam, R., A, (1985), 90 % of research area assigned into a hilly landform and the other 10 % was categorized into mountainous and valley landform on southwest.

3.3. Drainage Pattern

The drainage pattern has been categorized into three different group based on topographic map, river order, and observation in the field. They were then compared with basic and modified drainage pattern (Howard, 1967). They are classified into sub-parallel, parallel, and dendritic.

The sub-parallel covered around 70 % of the research area. The lithology in sub-parallel is dominated by mudstone from Rambatan Formation. On the other hand, the parallel pattern is in the long and continuous mountainous landform with steep slope area. The lithology is dominated by sandstone from Halang Formation, which is more resistant than Rambatan Formation. The summit of the mountain act as a water divided, and the river run from south to north. And the last one is dendritic pattern that covered the southeast and southwest of research area (Fig. 3).

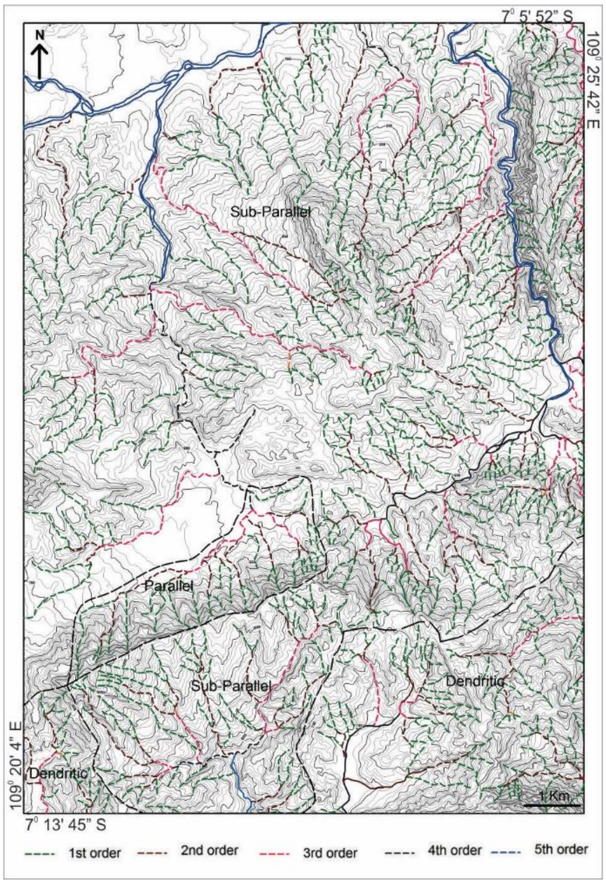

Fig. 3. Interpreted drainage pattern and river order.

The river order was categorized into five order. The smaller order represents the earliest stage of river development and becomes mature as the order escalate. Most river is dominated by first and second order. The third, fourth, and fifth order have the total of 20, 9, and 1, respectively. The river run along in two directions. The river on the south side is dominated by the river which run from north to south while the rest flow from south to north (Fig. 3).

3.4. Structural Geology

The folding is composed of two synclines (Mendelem and Majakerta) and two anticlines (Gombong and Karangmanggu). Most of the folding relatively extending from west to east except for Majakerta syncline which has a northwest-southeast direction.

The fault in the research location can only be observed from the map or satellite imagery. The fault interpretation was helped by the regional structural geology. It was interpreted that there are two local right-lateral fault. However, there was no slicken-side evidence in the field except the fractures. (one of the fractures is documented on Fig. 2C)

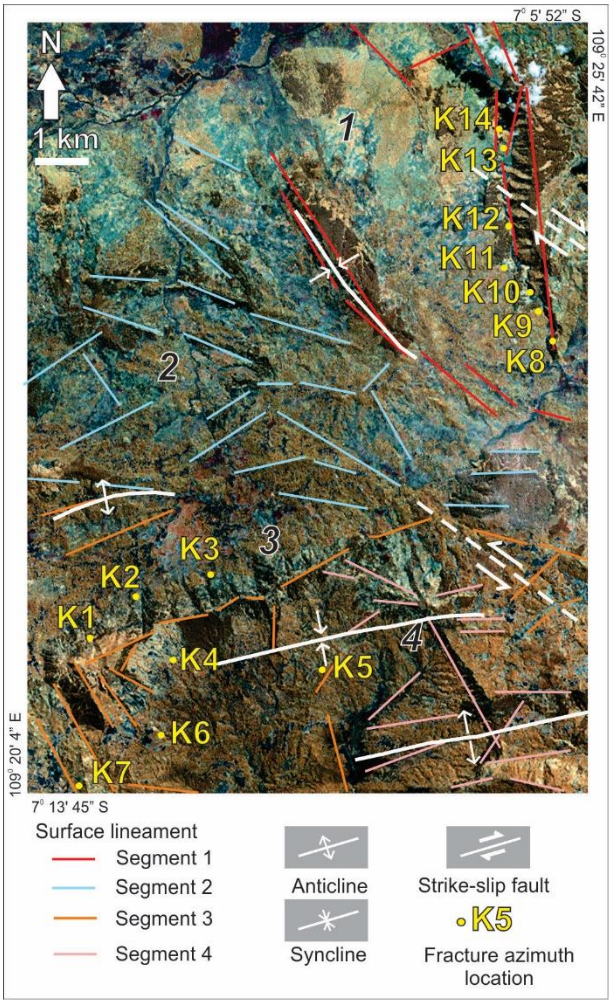

Fig. 4. Ridge lineament interpretation from satellite imagery has been divided into four segments. The fracture azimuth only available at the segment 1 and 3.

The fracture azimuth has been collected from 14 different stations in the southwest and northeast side of the study area (Fig. 4). But we were not able to measure the fracture azimuth in other area because the weathering rate was intensively occurred. Most of the fractures are located on the sandstone and no fracture was found on shale and igneous rocks. Field observation showed the direction of the fracture azimuth in two different dominant orientation, which are northeast-southwest and northwest-southeast. The fracture from the stereographic projection interpreted that it was dominated by the intermediate principle stress (Fig. 5). Then we assumed that the fracture found as shear component. However, in few stations we also found the tensional fractures.

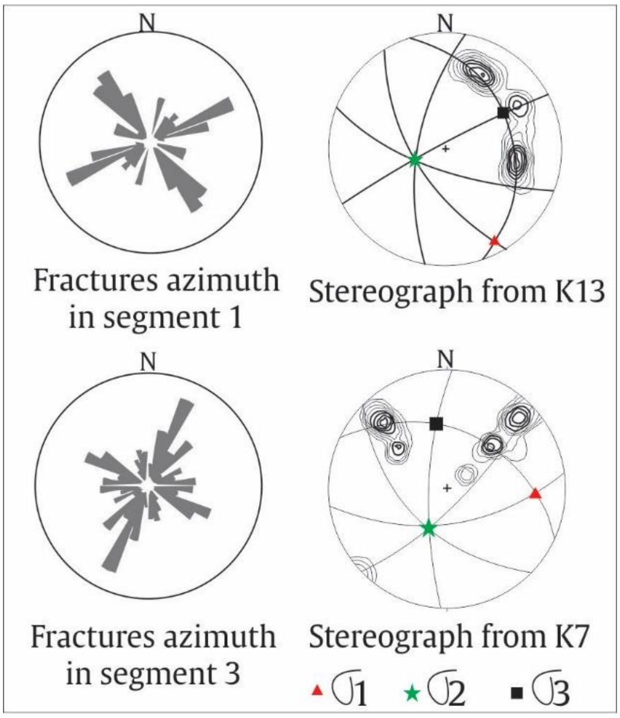

Fig. 5. Both principal stress from segment 1 and 3 interpreted as a result of strike-slip fault. The slicken-side has not been found in the field, only small displacement in the outcrop located at K13.

The fracture azimuth showed that the data distribution can not be represented in normal. The statistical calculation of the fracture azimuth direction is also represented by the same direction by field observation (Table 1).

3.5. The Lineament Trend

The lineament was mapped by utilizing the ridge and the river lineament from the satellite imagery and topographic map. Based on normality test of Kolmogorov-Smirnov, the lineament azimuth is not categorized into normally distributed data set.

The ridge lineament was drawn by considering a continuous morphological which formed by specific geological processes. Some of the ridge had a distinct shape but some hadnot. The differences acknowledge trough the color and the shadow from satellite imagery.

The mode of ridge lineament in each segment showed four different trends. Then the research area was divided into four different segments. Segment 1 is dominated by N 174^{0} E (northeast-southwest) while segment 2 is dominated by two different orientation, N 57^{0} E and N 121^{0} E (northeast-southwest and northwest-southeast). Segment 3 is directed into different trend direction, which is N 150^{0} E (northwest-southeast). And segment 4 was dominated by N 91^{0} E trend (west-east) (Fig. 6).

Table 1. Descriptive analysis of lineament and fracture azimuth.

Segmented of research area	Lineament and Fracture Trend	n	Median	Mode	Std. deviation
Segment 1	Ridge	104	147	174	49,55
	River	424	293	302	113,23
	Fracture	258	205,50	205	79,32
Segment 2	Ridge	144	104,50	57; 121	27,31
	River	439	154	69	63,48
Segment 3	Ridge	142	74	150	42,19
	River	289	135	157	44,94
	Fracture	169	140	140	92,46
Segment 4	Ridge	88	90	91	28,78
	River	124	131	67; 103; 200	81,74

The river lineament composed of two kinds set of data, longer and shorter. The longer river was located on several main river while the shorter one came with a great deal of number and dominated the river branching (Fig. 6). Most river lineament is dominated by the same pattern direction with the ridge in each segment and while the rest show opposite direction.

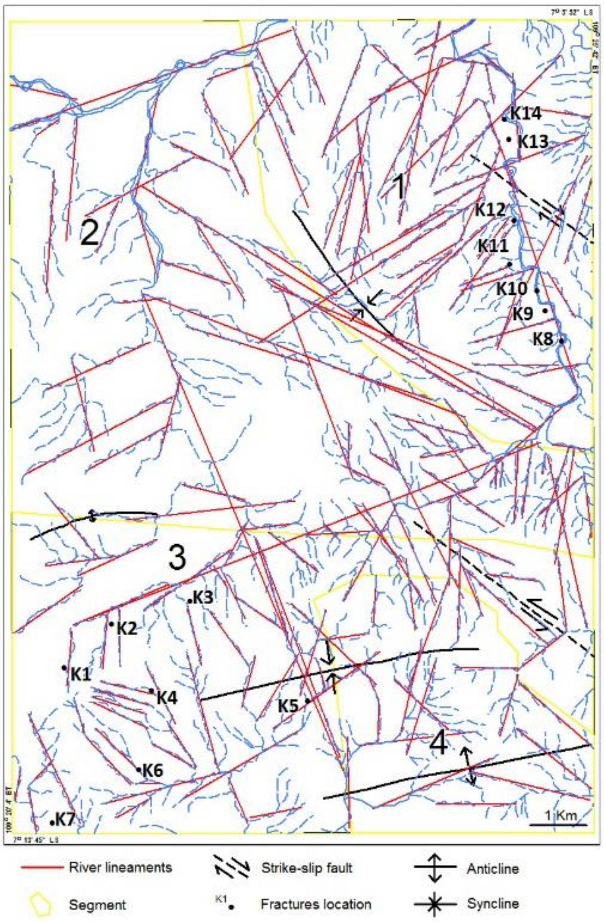

Fig. 6. River lineament and structural feature

3.6. Correlation between fracture azimuth, ridge and river lineament

All data set are not normally distributed, then the Spearman test performed. We found that there were plenty of which had different correlation, even if it was in the same segment.

In segment 1 we found that there was statistically significant correlation between fracture azimuth and ridge, and the correlation strength was categorized into medium. It also had the same significant correlation between ridge and river lineament, but it was the weak one.

In segment 2 there was only ridge and river lineament which compared to each other. They showed a meaningful correlation, but it was very weak.

Different with segment 1 and 2, the fracture and river lineament in segment 3 has a negative correlation and there was no correlation between fractures and ridge lineament in this segment.

Segment 4 was almost the same with segment 2, which only has ridge and river lineament to be compared. It showed no statistical correlation were found between these parameters.

We also compared fractures from segment 1 and 3 with the ridge and river lineament from outside this segment. But the result showed no significance, except the correlation between fracture in segment 3 with ridge in segment 4 which showed the negative correlation.

The correlation was also compared with fractures and corrected lineament. It was corrected to the main tectonic force angle, which was interpreted came from the north side of Java. After reducing the lineament with the main tectonic force, we got no significant changes using this method. Some of data which had no correlation remain the same. However, the negative correlation between fracture in segment 3 and ridge lineament in segment 4 become not significant.

Table 2. The correlation between segment. (Fr=fracture; Rd=Ridge; Rv=River. The number indicate the segment). *p < 0.05 and R (+) = Significant and linear correlation; **p < 0.05 and R (-) = Significant and opposite correlation; ***p > 0.05 = Not significant

Correlation intra and between segment	P (significant level)	R (Correlation Strength)
Fr1-Rd1 *	0.0	0.436
Fr1-Rv1 ***	0.882	0.09
Rd1-Rv1 *	0.03	0.293
Fr1-Rd2 ***	0.112	-0.133
Fr1-Rv1 ***	0.233	-0.74
Rd2-Rv2 *	0.001	0.278
Fr3-Rd3 ***	0.602	0.044
Fr3-Rv3 **	0.0	-0.324
Rd3-Rv3 ***	0.906	-0.10
Fr3-Rd4 **	0.0	-0.409
Fr3-Rv4 ***	0.13	-0.222
Rd4-Rv4 ***	0.187	0.142

4. Discussion

Regional tectonic at research location was interpreted between Paleocene and recent. Martodjojo (1994) grouped tectonic deformation in the research area into the Meratus and Sumatra trend which formed between Late Cretaceous and Paleocene. The oldest stratigraphy at research location was deposited from Middle to Late Miocene, which indicates that the fractures and lineaments must be younger than those regional strike-slip. We presumed that even there was time gap between regional strike-slip and geologic structures at the research location, the dominant lineament and fracture azimuth showed a similar pattern with right-lateral Cilacap-Pamanukan fault (northwest-southeast) and left-lateral Muria-Kebumen fault (northeast-southwest).

The main tectonic force tends to come from north, created a synthetic (R1) Muria-Kebumen and antithetic (R2) Cilacap-Pamanukan shear fault according to Reidel shears model. The principle stress from fractures (segment 1 and 3) showed that the intermediate stress was the dominant force which affected fractures direction. This result also had the same direction with the Indian oceanic subduction from the Late Cretaceous to the present.

Field observation has succeeded to classify the morphology based on its lithology. We found that most resistant rocks (sandstone from Halang Formation and granodiorite intrusion) are located on the mountainous landform at altitude more than 500 meters above sea level with sloping and slightly steep slope. However, some of the sandstone still can be found at the hilly landform together with mudstone from Rambatan Formation. This distribution showed that the weathering rate in the research location is increasing downward. The valley shape become an indicator for weathered rocks. Most sandstone and intrusion landform showed a sharp v-shaped valley (vertically eroded). Except for intrusion, the sandstone from the Halang Formation were distributed in a long and continuous mountain. On the other hand, the landform with mudstone and andesitic lava dominated by the u-shaped valley (horizontally eroded).

The statistical descriptive showed that most of the lineament and the fracture azimuth assembled into the second quadrant. However, several lineament and fractures fall into the first and third quadrant (see mode in Table 1). According to this information the lineament has two major direction, which are northwest-southeast and northeast-southwest. The fracture azimuth also has the same direction with the lineament. The fractures direction in segment 1 is represented by northeast-southwest direction, while the fracture from segment 3 dominated by northwest-southeast direction.

In segment 1 the river and ridge lineament tend to have northwest-southeast direction while the fracture has the northeast-southwest. The opposite direction between these parameters were caused by the less dominant of fracture azimuth direction (northwest-southeast). It was proved by the coefficient correlation that falls into medium category. However, the fracture might not the main influence because the slope is slightly steep, and the drainage pattern is sub-parallel, which means external factor could possibly have a role in this segment.

In the segment 2 and 4, neither the ridge nor the river has a correlation with the fracture from segment 1 and 3. Most likely the formation of ridge and river were controlled by the denudational process. We interpreted this was due to the absence of fractures. Moreover, the slope is categorized into sloping and the drainage pattern is dominated by sub-parallel.

The ridge, river, and fractures in segment 3 have the same direction. However, the significant correlation only resulted between fractures and river lineament. The fracture possibly less affected the formation of the river because the coefficient correlation has negative value, thus it might be not fully controlled by fractures or the fracture was not greater than external factors such as weathering. Insignificant correlation between fractures and ridge proved the lithology and external factor could possibly control the morphology in segment 3. Otherwise, the ridge could be influenced by less dominant fracture orientation, which was northeast-southwest. We were able to interpret this because one of the correlations between fracture and lineament still meaningful. However, if both of lineament do not have meaningful correlation to the fracture then no correlation will be significant statistically.

The correlation between calibrated and non-calibrated lineament showed no significance difference. This could possibly happen because the main tectonic force has only small angle value, thus the changes could not be significantly detected.

Our research limitation includes the absence of morphometric characteristic such as Bifurcation Ratio, Drainage Density, etc. It occurs since our research area was not big enough to discuss about the catchment area. Other factors that may become the limitation of our study are the absence of fault evidence that may affect the landform changes.

5. Conclusion

The regional fault in central Java compare to the lineament and fracture azimuth have the same direction with the research area, which is northwest-southeast and northeast-southwest. However, they have different dominant direction in each segment.

The lineament in segment 3, especially the river, was probably controlled by the Cilacap-Pamanukan fault. However, the negative correlation and field data showed that the weathering process also had a role on this lineament.

There is orientation difference between the fracture and lineament in segment 1. However, the correlation between ridge and river in this segment is weak and linear. The weak correlation showed that there might be another fault mechanism which affected the ridge and river lineament. Since the position of this research area in the middle of two strike-slip regional fault, there is a possibility that the landform was built with different lineament orientation. The direction possibly caused by another regional fault which is Muria-Kebumen fault.

Based on statistical calculation, the morphology of the research area was not probably fully controlled by the regional fault. Evidence in the field also showed the external factors such as erosion as the factor of changes in landform (proved by weathered shale of Rambatan Formation from Fig. 2B).

The river order is dominated by lower order, which characterizes the younger rivers. The vertical erosion dominated the weathering processes, indicated by the great number of lower river order. The drainage pattern also showed less significant effect to be affected by the fault. Observation from the field showed that only three synclines and two anticlines that were probably affecting the landform change.

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