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Morphometric analysis of relative tectonic activity in the Baturagung Mountain, Central Java, Indonesia

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Abstract. Special Region of Yogyakarta and Klaten district, Central Java is one of areas in Indonesia that is prone to earthquake caused by subduction in Indian Ocean and active fault in land. The earthquake sources from active fault probable from Opak and other faults located in Baturagung Mountain. Active faults controlling landform development in tectonically active regions, and it has significantly affected fluvial systems and mountain – front landscapes in the Baturagung Mountain. To assess tectonic activities in the area used quantitative analysis (morphometric). Morphometric analysis consists of 5 parameters geomorphic indices: drainage basin asymmetry (AF), hypsometric curve and integral (Hc and Hi), stream length gradient (SL) index, basin shape index (Bs), and mountain-front sinuosity (Smf). These indices were combined to yield the relative tectonic activity index (RTAI) using geographic information systems (GIS). The result found that RTAI in the study area are divided into three classes: Class 2 (high 0.6% of the watershed area (1.32 km^2)); Class 3 (moderate 58.9% (122.1 km^2)); and Class 4 (low 40.4% (83.75 km^2)). All of morphometric analysis generally indicates this area more influenced by tectonics than erosion. The results are consistent with geomorphological observations.

Keywords: Baturagung Mountain; geomorphic indices; morphometric; active fault.

1. Introduction

Tectonic geomorphology is defined as the study of landforms produced by tectonic processes, or the application of geomorphic principles to the solution of tectonic problems [1]. The quantitative measurement of landscape is based on the calculation of geomorphic indices using topographic maps, aerial photographs and field work. The results of several indices can be combined in order to highlight tectonic activity and to provide an assessment of a relative degree of tectonic activity in an area [1].

Baturagung Mountain is located in Central Java area. This area is one of areas in Indonesia vulnerable to earthquake from subduction zone in Indian Ocean and active fault in land. One of the destructive earthquake sources is from active fault. Destructive earthquake events occurred in this area caused by active fault on 1867, 2006 and 2010 [2].

Opak fault in SE – NW direction inferred as a source of earthquake in this area. In addition there are other faults located in mountain – front zone North of Baturagung which is expected to contribute to the southern Klaten damage [3]. In general, faults that caused earthquake is located in Baturagung Mountain. Therefore, the analysis of this area was related to Baturagung Mountain.

The purpose of this study was to assess tectonic activities of Baturagung Mountain. The activities of Baturagung Mountain would be analyzed using quantitative analysis (morphometric).

2. Data and Method

Data used in this study are Shuttle Radar Topography Mission digital elevation model (SRTM DEM) data with spatial resolution of 30 m which is available freely from the USGS website [4], geological map (Yogyakarta and Surakarta – Giritontro sheets) data from geological research and development centre [5,6], and topographical map data from geospatial information agency [7]. All of the data were used to calculated geomorphic indices in morphometric analysis.

Morphometry is defined as quantitative measurement of landscape shape. At the simplest level, landforms can be characterized in terms of their size, elevation (maximum, minimum or average), and slope. Quantitative measurements allow geomorphologists to objectively compare different landforms and to calculate less straightforward parameters that may be useful for identifying a particular characteristic of an area such as level of tectonic activity [1].

This study applied morphometric analysis in Baturagung Mountain to evaluate relative tectonic activity rates. Considering the diversity of the morphotectonic features [1], we analyzed five geomorphic indices: drainage basin asymmetry (AF), hypsometric curve and integral (Hc and Hi), stream length gradient index (SL), basin shape index (Bs), and mountain – front sinuosity (Smf). All of parameter values computed in a single index as relative tectonic activity index (RTAI) [8] to characterize relative tectonic activity. Morphometric analysis used spatial tools geographic information systems (GIS) arcGIS 10 software and Microsoft Excel. This kind of methodology has been used to analyze various active areas such as Sarvestan area, Iran [8], Cimandiri Fault, Indonesia [9] and Lembang Fault, Indonesia [10]. The results from morphometric analyses were also validated in field based on geomorphological observations.

3. Result and Discussion

3.1. Morphometric analyses

Morphometric analyses were used to identify relative rates of active tectonics in study area. Five geomorphic indices parameters were analysed, including drainage basin asymmetry (AF), hypsometric integral (Hi), stream length gradient index (SL), basin shape index (Bs), and mountain-front sinuosity (Smf) [1,8]. Result of geomorphic indices values were classified into three classes tectonic activity: Class 1 (more active), Class 2 (active) and Class 3 (less active) (Table 1) [8]. Most of these indices are obtained for river basins. Two major rivers flow in study area (Dengkeng River and Oyo River) were subdivided into 65 subbasins.

Table 1. Relative tectonic activity index (RTAI) based on morphometric parameters [8].

No.	Morphometric Parameters	Relative tectonic activity index		
		Class 1	Class 2	Class 3
1	SL	$SL \geq 500$	$300 \leq SL < 500$	$SL < 300$
2	Hi	$Hi \geq 0.5$	$0.4 \leq Hi < 0.5$	$Hi < 0.4$
3	Bs	$Bs \geq 4$	$3 \leq Bs < 4$	$Bs \leq 3$
4	AF	$AF \geq 65$ or $AF < 35$	$35 \leq AF < 43$ or $57 \leq AF < 65$	$43 \leq AF < 57$
5	Smf	$Smf < 1.1$	$1.1 \leq Smf < 1.5$	$Smf \geq 1.5$

3.1.1. Drainage basin asymmetry (AF)

The drainage basin asymmetry (AF) can be used to evaluate tectonic tilting at the scale of a drainage basin [1]. AF defined as (1):

$$AF = 100\,(Ar/At) \tag{1}$$

Ar is the area of a part of a watershed on the right of the master stream and At is the total area of the watershed. AF equal about 50 indicate tectonic relatively stable, AF greater or less than 50 may suggest tilt [1]. In the study area AF varies from 23.97 (subbasin 60) to 86.13 (subbasin 9). AF values were grouped into three classes: 1 (AF≥65 or AF<35), 2 (35≤AF<43 or 57≤AF<65), and 3 (43≤AF<57) [8] (Figure 1; Table 2). Class 1 and 2 of AF dominantly located at faults zone (Figure 1).

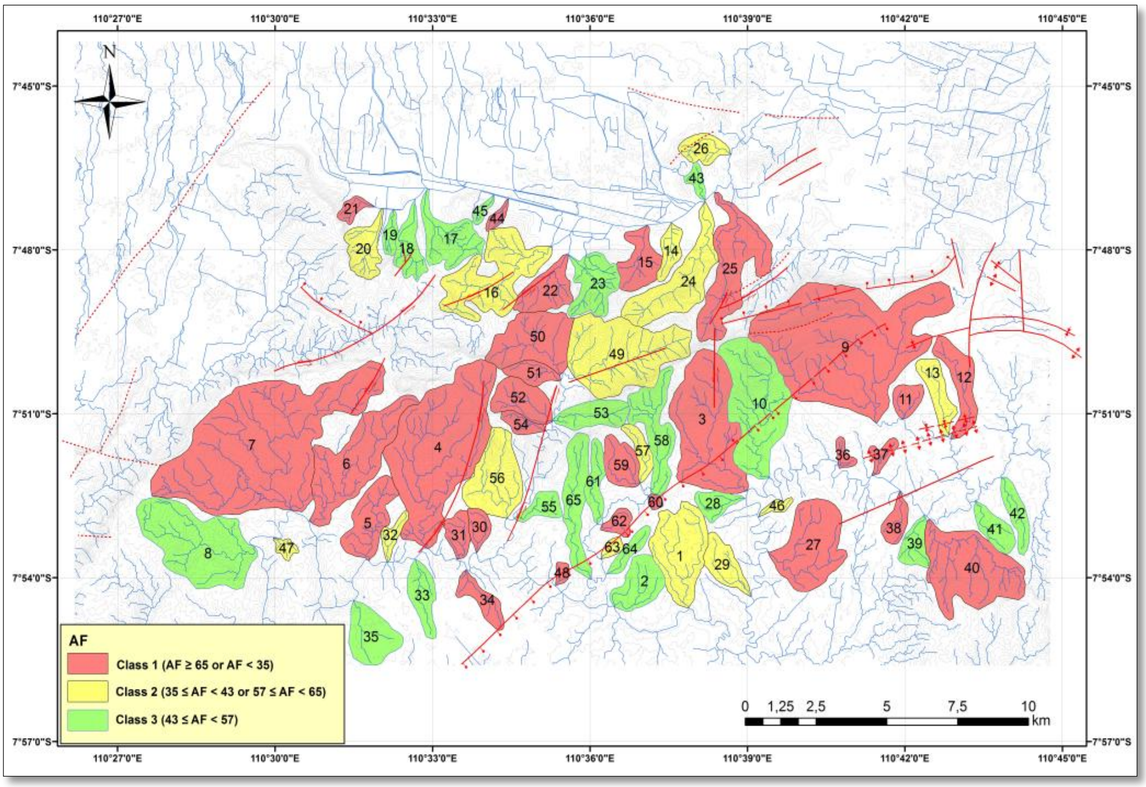

Figure 1. Map of AF analyses. Colour red, yellow, and green area indicate class 1, class 2, and class 3.

3.1.2. *Hypsometric curve and integral (Hc and Hi)*

The hypsometric integral (Hi) describes the relative distributions of elevations in a given area of a landscape particularly a drainage basin. The index is defined as the relative area below the hypsometric curve and thus expresses the volume of a basin that has not been eroded. A simple equation to approximately calculate the index is (2):

$$Hi = (\text{average.elev.} - \text{min.elev.}) / (\text{max.elev} - \text{min.elev}) \quad (2)$$

Hi can be used as an indicator of a landscape stage in the cycle of erosion and divided into 3 stages: young, mature, and old. In the study area Hi varies from 0.16 (subbasin 16) to 0.8 (subbasin 35). Hi values were grouped into three classes with respect to the convexity or concavity of the hypsometric curve (Hc): Class 1 with convex hypsometric curves (Hi≥0.5), indicates young stage; Class 2 with concave-convex hypsometric curves (0.4≤Hi<0.5), indicate mature stage; and Class 3 with concave hypsometric curves (Hi<0.4), indicate old stage [1] (Figure 2; Figure 3; Table 2). Calculation of Hi indicated area of study influenced by erosion, tectonic and rock resistance.

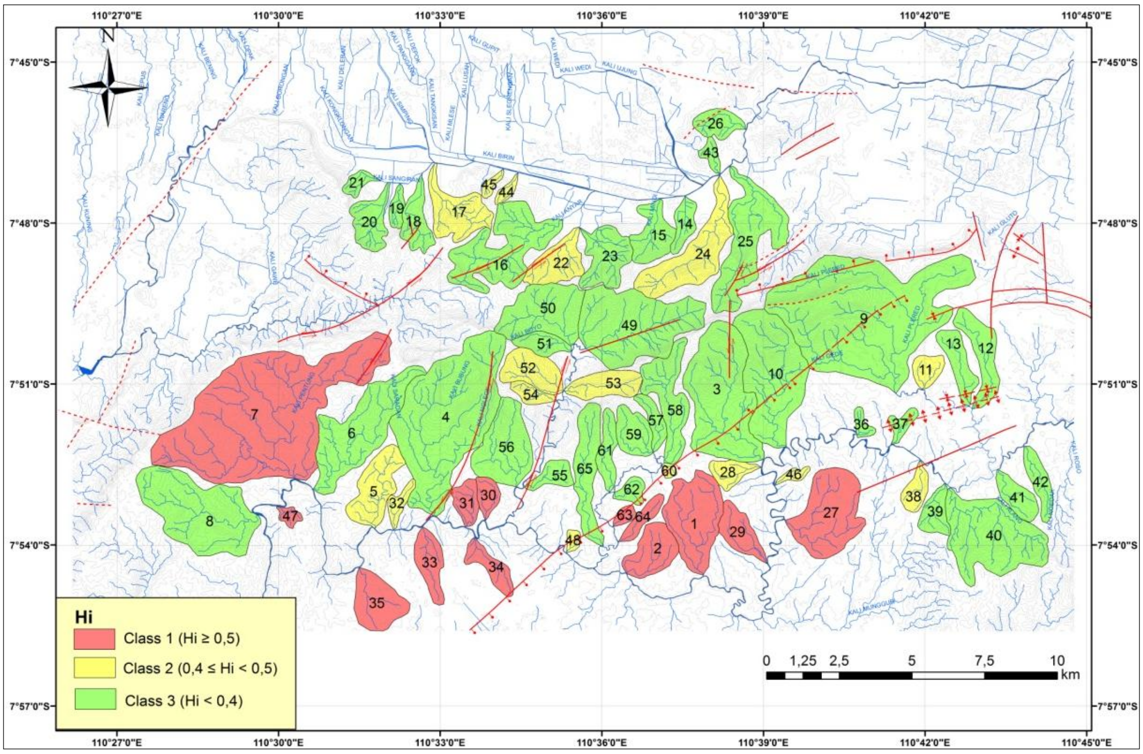

Figure 2. Map of Hi results. Colour red, yellow, and green area indicate young, mature, and old stages.

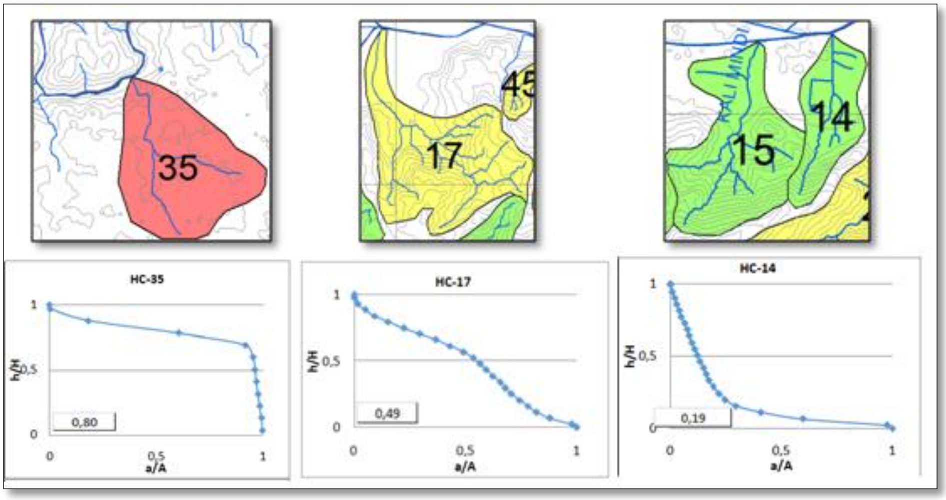

Figure 3. Hypsometric curves of three subbasins.

3.1.3. Stream length gradient index (SL)

SL correlates to stream power. SL index is sensitively to change in channel slope by tectonic activity, rock resistance, and topography. SL index defined as (3):

$$SL = (\Delta H/\Delta L)\ L \tag{3}$$

$\Delta H/\Delta L$ is the channel slope and L is the total channel length from the watershed divide to midpoint of the reach. The SL index can be used to evaluate relative tectonic activity. Although an area on soft rocks with high SL values indicates recent tectonic activity, anomalously low values of SL may also represent such activity when rivers and stream flow through strike – slip fault. High SL value indicates that valley profile steeply, deep incision, and possible as a fault zone and represent tectonic activity [1]. Lithology in study area is related to rock resistance which showed in geological map (Figure 4).

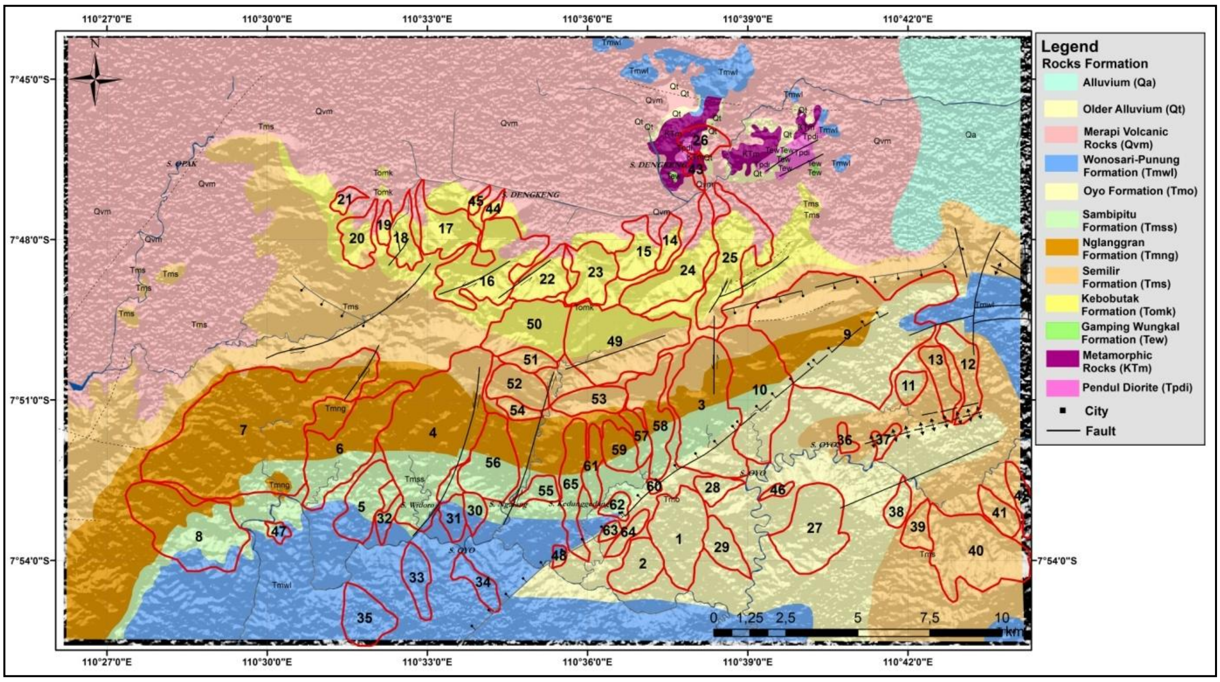

Figure 4. Geological map of study area.

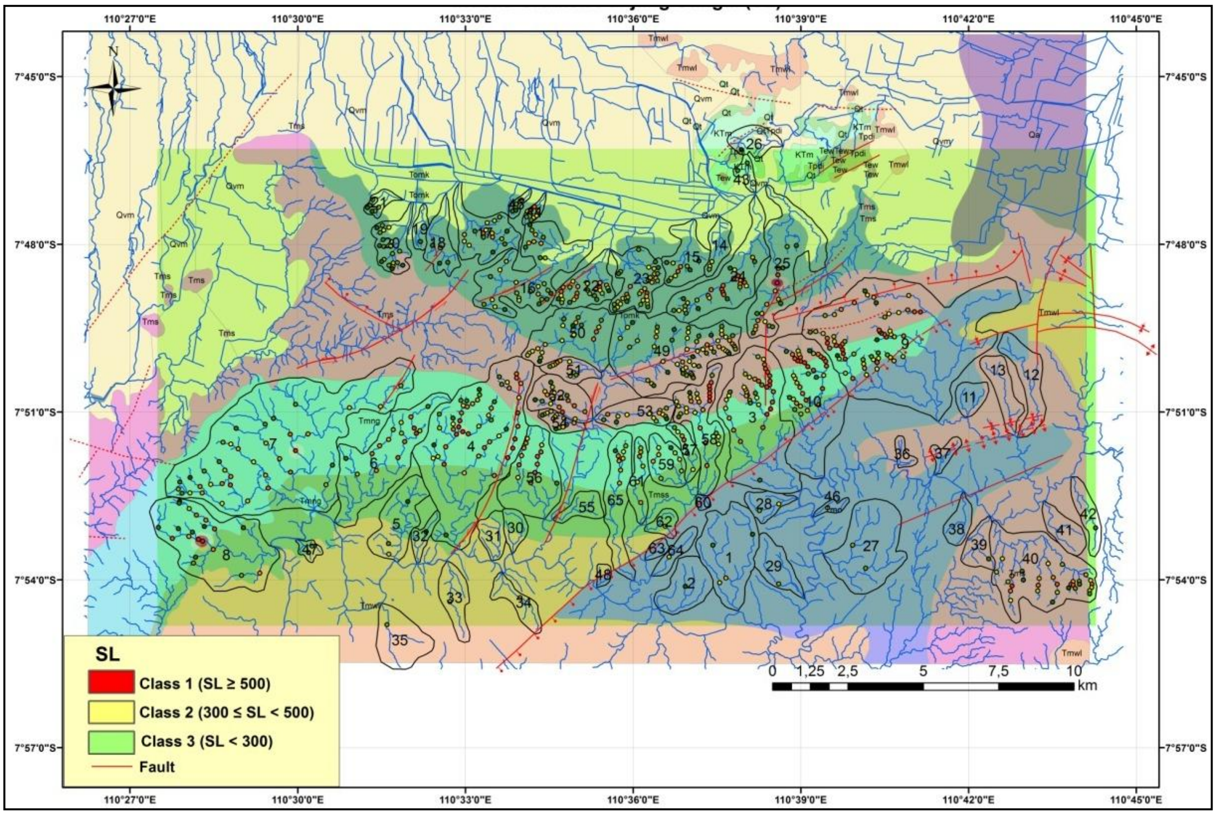

Figure 5. SL index along the drainage network. Contour area red, yellow and green area indicate class 1, class 2, and class 3.

SL is calculated along rivers using a digital elevation model (extracted from a digitized 1:25000 topographic map) and GIS (Figure 5 and 6) to compute its value for each subbasin. The value ranges from 16.70 to 995.85. The values were classified into three categories: Class 1 (SL≥500), Class 2 (300≤SL<500) and Class 3 (SL<300) [1]. The result of the classification is shown in Table 2. Calculation of SL at subbasins show high additional value with steep topography that flowed by the stream. The high changing of SL value occurred because of structural zone not because of lithological changing.

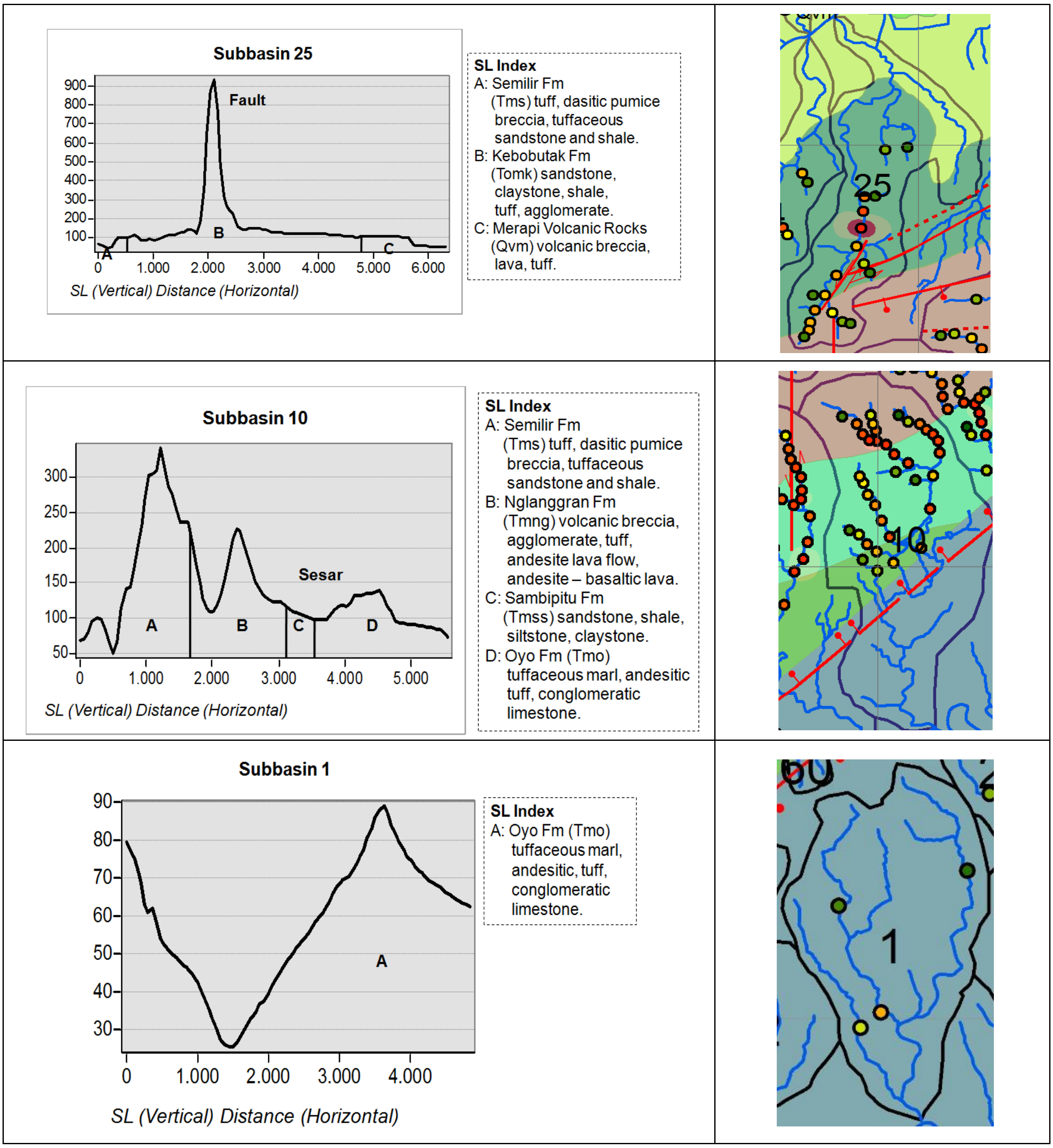

Figure 6. Longitudinal river profiles and measured SL values for three subbasins in the study area.

3.1.4. Basin shape index (Bs)

The horizontal projection of a basin may be described by the basin shape index or the elongation ratio, Bs defined as (4):

$$Bs = B_l / B_w \tag{4}$$

B_l is the length of a basin measured from the highest point and B_w is the widest point. Relatively young drainage basins in tectonically active areas tend to be elongated in shape, normal to the topographic slope of mountain [1].

Bs was computed using DEM and classified into three classes: 1 ($Bs \geq 4$), 2 ($3 \leq Bs < 4$) and 3 ($Bs \leq 3$) [4]. Bs ranges from 0.44 (subbasin 36) to 6.31 (subbasin 65). The result of the classification is shown in (Figure 7; Table 2). Generally, based on Bs analysis, study area dominated by class 3, presence of class 1 and class 2 were influenced by tectonic activity at subbasin.

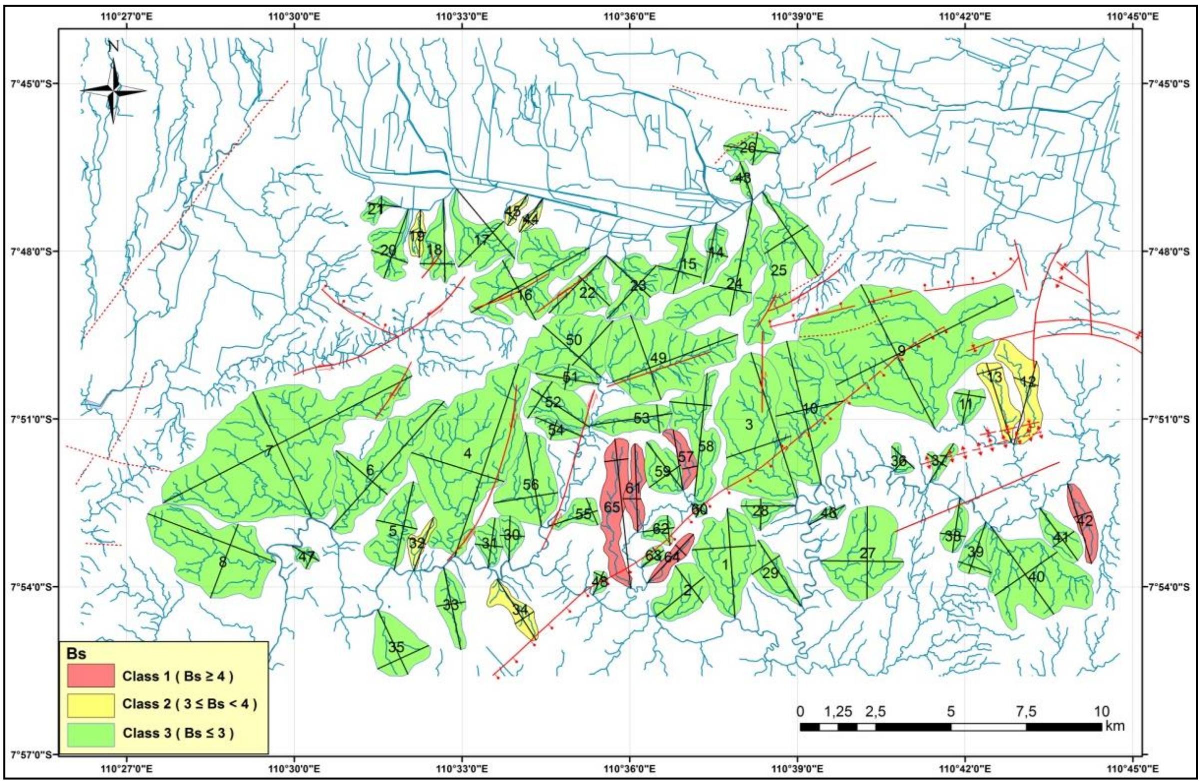

Figure 7. Basin shape index. Colour red, yellow, and green area indicate class 1, class 2, and class 3.

3.1.5. *Mountain – front sinuosity (Smf)*

Mountain-front sinuosity is defined as a topographic transition zone between mountains and plain [11]. Smf is define as (5):

$$Smf = Lmf/Ls \tag{5}$$

Lmf is the length of the mountain front along the foot of the mountain, at the pronounced break in slope; and Ls is the straight line length of the mountain-front. Smf index reflects the balance between erosional forces that tend to cut embayment into a mountain-front and tectonic forces that tend to produce straight mountain front coincident with an active range bounding range [4]. The value of Smf can be detected by tectonic activity. The low value of Smf is associated with active tectonics and uplift. High value of Smf associated with reduces of uplift and erosional processes that will carve a more irregular mountain-front [8].

The values of Smf was calculated for 17 mountain front (Figure 8; Table 2) using Smf and Ls values measured from SRTM image, and divided into three classes: 1 (Smf<1.1), 2 (1,1≤Smf<1.5), and 3 (Smf≥1.5). Smf values ranges from 0.99 to 4.12. Generally, class 1 and class 2 of Smf occurred with structural zone in study area.

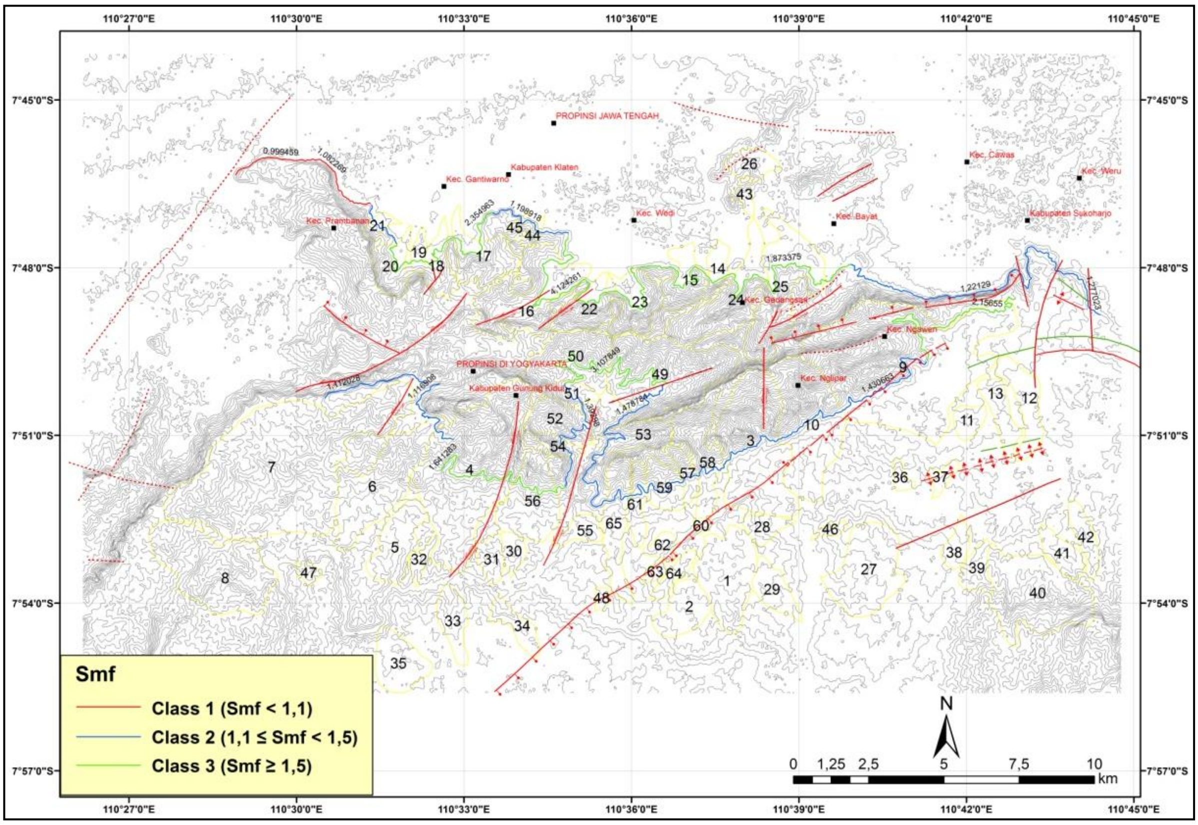

Figure 8. Smf index. Colour red, blue, and green indicate class 1, class 2, and class 3.

3.2. Spatial distribution of index values

Five morphometric parameters and lineament have been calculated to analyze the activity of Baturagung Mountain. The result found that AF is far from value 50 indicates the presence of tectonic tilting, hypsometric curve shows that this area belongs to young-mature topography, SL more than 300 indicating of active tectonic, Bs ≥ 4 indicating elongated shape of basin related to active tectonic, and Smf value is less than 1.5 indicating straight of mountain-front sinuosity as a lineament fault zone.

This study tried to evaluate tectonic activity in Baturagung area by using some of geomorphological parameters. The average of the five parameter measured geomorphic indices (RTAI) was used to evaluate the distribution of relative tectonic activity in the study area [8]. The values of the index were divided into four classes to define the degree of active tectonics: 1 – very high (1.0≤RTAI<1.5); 2 – high (1.5≤RTAI<2.0); 3 – moderate (2.0≤RTAI<2.5); and 4 – low (2.5≤RTAI) [8].

The distribution of the four classes is shown in Figure 9 and Table 2 shows the result of the classification for each subbasins. About 0.6% of the basin area (about 1.32 km^2) belongs to Class 2; 58.9% (122.1 km^2) to Class 3; and 40.4% (83.75 km^2) to Class 4.

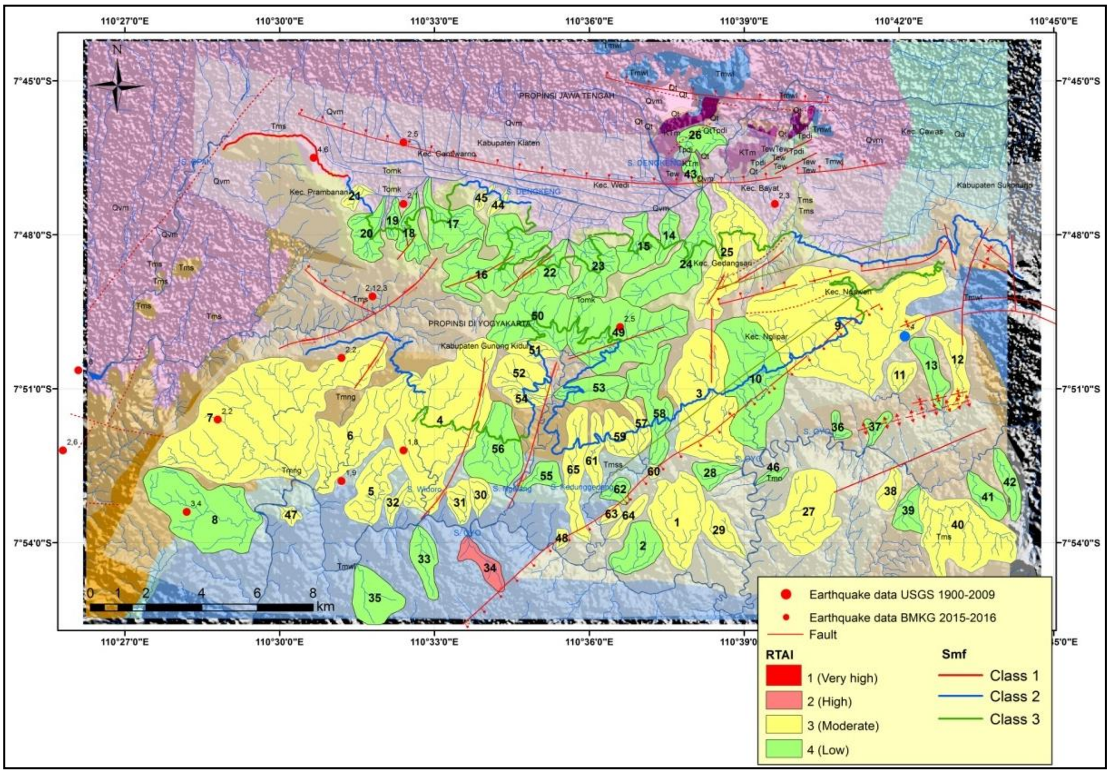

Figure 9. Relative tectonic activity index (RTAI) map. Colour pink, yellow, and green area indicate class 2, class 3, and class 4.

4. Conclusions

The result found that RTAI in the study area are divided into three classes: Class 2 (high 0.6% of the watershed area (1.32 km^2)); Class 3 (moderate 58.9% (122.1 km^2)); and Class 4 (low 40.4% (83.75 km^2)). All of morphometric analysis generally indicates this area is more influenced by tectonics than erosion. The results are consistent with geomorphological observations (Figure 10). Class 3 is with more steep hills than Class 4.

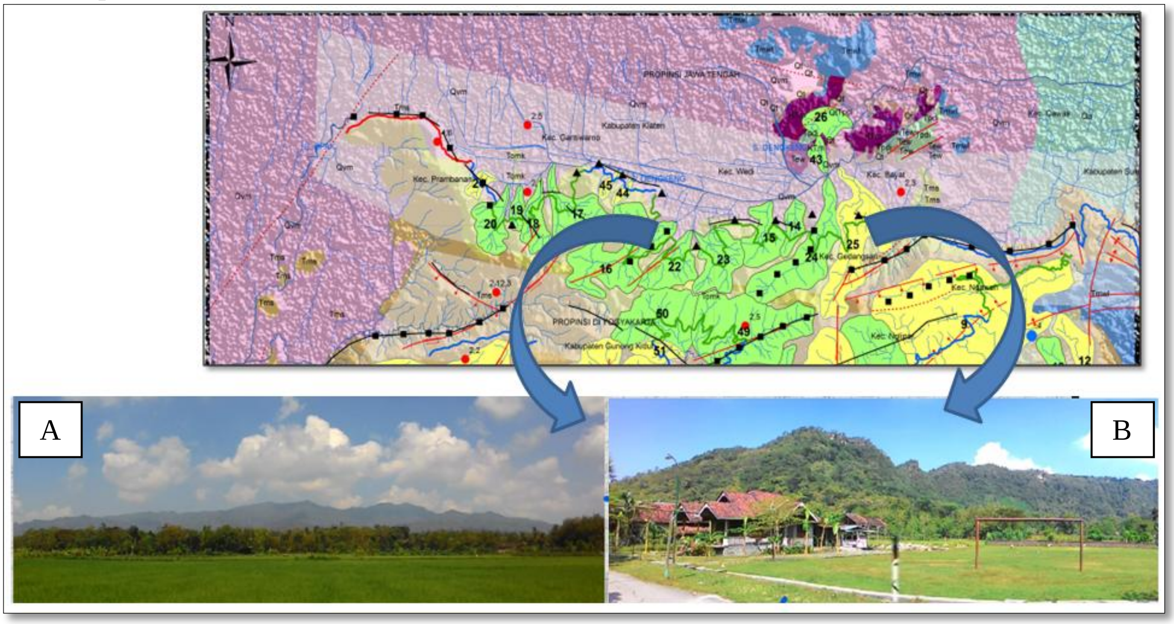

Figure 10. Geomorphological observations; Class 4 (A) and Class 3 (B).

Table 2. Values and classes of RTAI.

Subbasin no.	At (km^2)	Morphometric Parameters					Sum	RTAI	RTAI Class	
		Hi	AF	SL	Bs	Smf				
1	5.0	1	2	3	3		9	2.3	3	Oyo Fm
2	2.4	1	3	3	3		10	2.5	4	Oyo Fm
3	9.0	3	1	1	3	2	10	2.0	3	Oyo Fm, Sambipitu Fm, Ngalanggran, Semilir Fm
4	14.1	3	1	2	3	3	12	2.4	3	Sambipitu Fm, Ngalanggran, Semilir Fm
5	3.0	2	1	3	3		9	2.3	3	Wonosari-Punung Fm, Sambipitu Fm
6	6.6	3	1	2	3	2	11	2.2	3	Sambipitu Fm, Ngalanggran Fm
7	22.1	2	1	2	3		8	2.0	3	Sambipitu Fm, Ngalanggran Fm
8	8.3	3	3	1	3		10	2.5	4	Sambipitu Fm, Ngalanggran Fm, Wonosari-Punung Fm
9	20.3	3	1	1	3	2	10	2.0	3	Oyo Fm, Ngalanggran, Semilir Fm
10	78	3	3	2	3	2	13	2.6	4	Oyo Fm, Sambipitu Fm, Ngalanggran, Semilir Fm
11	1.0	2	1	3	3		9	2.3	3	Oyo Fm, Semilir Fm
12	2.4	3	1	3	2		9	2.3	3	Oyo Fm, Semilir Fm
13	1.7	3	2	3	2		10	2.5	4	Semilir Fm
14	1.0	3	2	3	3	3	14	2.8	4	Kebobutak Fm, Merapi Volcanic Rocks
15	2.2	3	1	3	3	3	13	2.6	4	Kebobutak Fm, Merapi Volcanic Rocks
16	6.3	3	2	3	3	3	14	2.8	4	Kebobutak Fm, Merapi Volcanic Rocks
17	2.9	2	3	3	3	3	14	2.8	4	Kebobutak Fm, Merapi Volcanic Rocks
18	1.7	3	3	3	3	3	15	3.0	4	Kebobutak Fm, Merapi Volcanic Rocks
19	0.6	3	3	3	2	3	14	2.8	4	Kebobutak Fm, Merapi Volcanic Rocks
20	1.9	3	2	3	3	3	14	2.8	4	Kebobutak Fm, Merapi Volcanic Rocks
21	0.6	3	1	3	3	2	12	2.4	3	Kebobutak Fm, Merapi Volcanic Rocks
22	2.3	3	1	3	3	3	13	2.6	4	Kebobutak Fm, Merapi Volcanic Rocks
23	2.8	3	3	3	3	3	15	3.0	4	Kebobutak Fm, Merapi Volcanic Rocks
24	4.8	2	2	3	3	3	13	2.6	4	Kebobutak Fm, Merapi Volcanic Rocks
25	5.9	3	1	1	3	3	11	2.2	3	Kebobutak Fm, Merapi Volcanic Rocks, Semilir Fm
26	1.3	3	2	3	3		11	2.8	4	Metamorphic rocks, Diorite, Merapi Volcanic Rocks, Older Alluvium
27	5.5	1	1	3	3		8	2.0	3	Oyo Fm
28	1.1	2	3	3	3		11	2.8	4	Oyo Fm
29	1.8	1	2	3	3		9	2.3	3	Oyo Fm
30	0.8	1	1	3	3		8	2.0	3	Wonosari-Punung Fm, Sambipitu Fm
31	1.1	1	1	3	3		8	2.0	3	Wonosari-Punung Fm, Sambipitu Fm
32	0.7	2	2	3	2		9	2.3	3	Wonosari-Punung Fm, Sambipitu Fm
33	1.7	1	3	3	3		10	2.5	4	Wonosari-Punung Fm
34	1.3	1	1	3	2		7	1.8	2	Wonosari-Punung Fm
35	2.7	1	3	3	3		10	2.5	4	Wonosari-Punung Fm
36	0.4	3	1	3	3		10	2.5	4	Semilir Fm
37	0.6	3	1	3	3		10	2.5	4	Semilir Fm, Oyo Fm
38	1.0	2	1	3	3		9	2.3	3	Oyo Fm
39	1.2	3	3	3	3		12	3.0	4	Semilir Fm
40	7.3	3	1	2	3		9	2.3	3	Semilir Fm
41	1.4	3	3	3	3		12	3.0	4	Semilir Fm
42	1.3	3	3	3	1		10	2.5	4	Semilir Fm
43	0.5	3	3	3	3		12	3.0	4	Metamorphic rocks, Merapi Volcanic Rocks
44	0.4	2	1	3	2	2	10	2.0	3	Kebobutak Fm, Merapi Volcanic Rocks
45	0.3	2	3	3	2	2	12	2.4	3	Kebobutak Fm, Merapi Volcanic Rocks
46	0.4	2	2	3	3		10	2.5	4	Oyo Fm
47	0.4	1	2	3	3		9	2.3	3	Wonosari-Punung Fm, Sambipitu Fm
48	0.3	2	1	3	3		9	2.3	3	Wonosari-Punung Fm, Oyo Fm
49	8.5	3	2	3	3	3	14	2.8	4	Kebobutak Fm, Semilir Fm
50	4.5	3	1	3	3	3	13	2.6	4	Kebobutak Fm, Semilir Fm
51	1.1	3	1	3	3	2	12	2.4	3	Semilir Fm
52	2.3	2	1	3	3	2	11	2.2	3	Semilir Fm
53	2.0	2	3	3	3	2	13	2.6	4	Semilir Fm
54	0.7	2	1	3	3	2	11	2.2	3	Semilir Fm
55	1.0	3	3	3	3		12	3.0	4	Sambipitu Fm
56	4.3	3	2	3	3	3	14	2.8	4	Sambipitu Fm, Ngalanggran Fm
57	0.9	3	2	3	1	2	11	2.2	3	Sambipitu Fm, Ngalanggran Fm
58	3.5	3	3	2	3	2	13	2.6	4	Sambipitu Fm, Ngalanggran Fm
59	1.7	3	1	3	3	2	12	2.4	3	Sambipitu Fm, Ngalanggran Fm
60	0.2	2	1	3	3		9	2.3	3	Sambipitu Fm, Oyo Fm
61	1.3	3	3	3	1	2	12	2.4	3	Sambipitu Fm, Ngalanggran Fm
62	0.7	3	1	3	3		10	2.5	4	Sambipitu Fm, Oyo Fm, Wonosari-Punung Fm
63	0.4	1	2	3	3		9	2.3	3	Oyo Fm, Wonosari-Punung Fm
64	0.8	1	3	3	1		8	2.0	3	Oyo Fm
65	3.1	3	3	3	1	2	12	2.4	3	Nglanggran Fm, Sambipitu Fm, Oyo Fm, Wonosari-Punung Fm

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