Geomorphic Analysis in Determining Tectonic Activity Affected by Sumatra Fault in Liwa Region and Its Surrounding Area, Lampung, Indonesia

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Abstract - The study discusses about characteristics of Sumatra Fault and its tectonic activity in Liwa and the adjacent area. The research uses quantitative methods of verification hypothetical deduction, which starts from the general approach, then it pursues into more specialized and focused ones. While the research work includes field measurements, remote sensing with GIS, and geomorphologic analysis using morphometry, such as: sinuosity of mountain front (Smf), percentage of facets, ratio of the width and height of the valley (Vf), bifurcation ratios of the river (Rb), drainage density (Dd), shape of the watershed basin area (Bs), hypsometric curves (HI), and gradient index of stream length (SL). Basically, two blocks separated by the Sumatra Fault do not have a significant difference in tectonic activity, but the tectonic activity change can be seen when the studied area is divided into three blocks (northwest, middle, and southeast), then the change in each part can clearly be seen. Apparently, the tectonic activity in the studied area starts from the southeast continues toward the northwest. It is proved by this research, that geomorphological parameters which are associated with mountain fronts and watershed systems demonstrate the value of the activity increases towards the northwest. Hypsometric curves and a river analysis show that the tectonic activity in the northwest is relatively in a young stage, while towards the southeast it is getting in a mature stage.

Keywords: Sumatra Fault, active tectonic, morphology, morphometry, earthquake

INTRODUCTION

Sumatra Fault is an active fault in Sumatra Island which has right lateral movement (dextral), with approximately ~1,900 km length, divided into 19 fault segments, with 60 to 200 km length each (Sieh dan Natawidjaja, 2000; Natawidjaja dan Triyoso, 2007). One of them is Kumering Fault segment which is located at 5°30'S - 4°35'S, 150 km length, from Kumering River it crosses the Liwa City to Suwoh (Natawidjaja, 2002).

Historically, this Kumering Fault segment has produced several large earthquakes, including the one occurred on June 25, 1933 (Ms 7.5) in Liwa region (Katili and Hehuwat, 1967), and February 15, 1994, that caused fatalities up to 300 people, injured 4,000 and 2,000. The loss caused by the destroyed physical buildings costs about one trillion rupiahs (Dini *et al*., 2003).

The Sumatra Fault is unique, because it divides the island into two large blocks, which are northeastern and southwestern blocks. The

problem that arises are, how tectonic character worked on each of these blocks? How were the conditions geomorphically formed in the whole region? In this article, the tectonic character in both blocks will be discussed, then the whole region is divided into three parts (northwest, middle, and southeast). The morphometric approach is applied based on the formation of mountains and watersheds which are sensitive to tectonic treatment. Thus, both qualitative and quantitative studies could be carried out.

The tectonic of Sumatra Fault gives a very strong influence to Liwa and its surrounding area. It can be seen from the appearance of typical geomorphic indices formed by active faults (Keller, 1986), for instances river offsets, straightness river segments, fault scarp, V-shape valleys, and sag ponds.

The researched area is located in Liwa City and its surrounding area, West Lampung Regency, Lampung Province. Based on its geographical position, the studied area is located at 103°45'E - 104° 30'E and 4°45'S - 5°15'S (Figure 1).

METHODS

Morphotectonic is a study of all relationships between structural geology and landform, or more specifically, it is the relationships between the structure of neotectonic (active faults) and landform (Stewart and Hancock, 1994). Morphotectonic is influenced by morphology and tectonic processes occurred in the past, because morphology has the dimension of space, while tectonic has the dimension of time. Tectonic landforms express morphological formations that can be used as indicators of the occurrence of tectonic movements (tectonic activity).

Morphometry is a quantitative measurement of a landscape shape following the rules of geomorphological landforms as objects of comparison and calculation parameters. It is very useful for identifying characteristics of an area and level of a tectonic activity (Keller and Pinter, 1996). The basic theory of a morphometric analysis involves relative adjustments between local base-level processes (tectonic uplift, stream
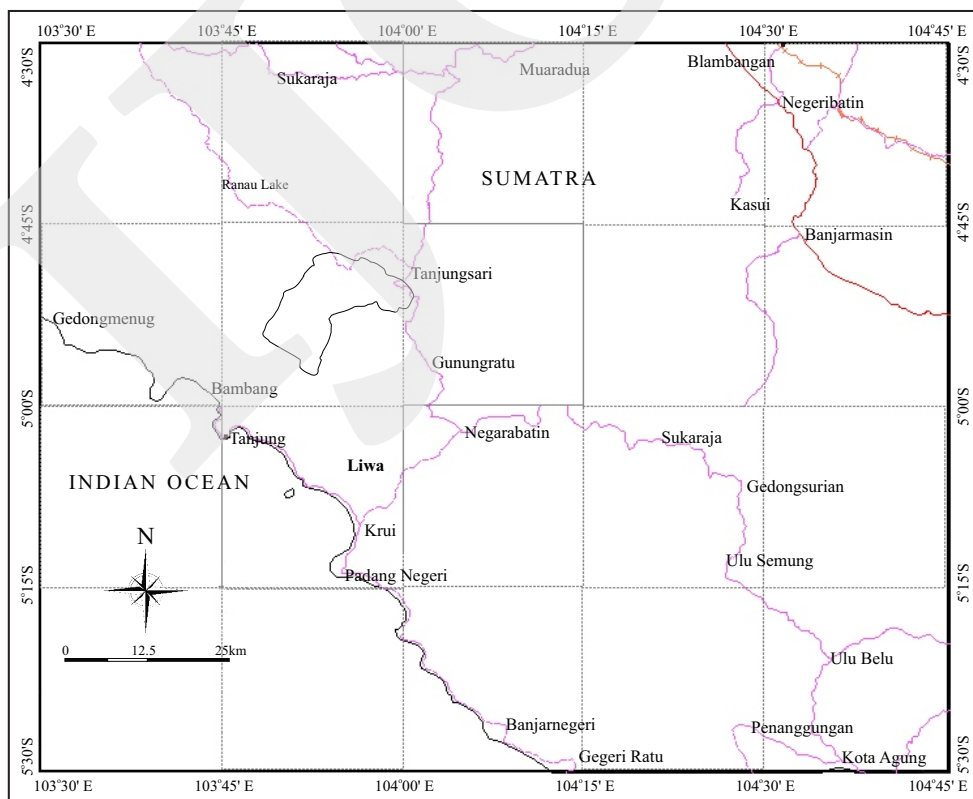

Figure 1. Locality map of study area.

downcutting, basin sedimentation, and erosion) and fluvial systems which cross structurally controlled topographic mountain fronts (Bull and McFadden, 1977).

Eight major study areas comprising mountain fronts and the fluvial system are applied in this morphometric analysis, such as: mountain fronts sinuousity (Smf), facets, valley floor width and valley height ratio (Vf), drainage basin shape (Bs), bifurcation ratio (Rb) and drainage density (Dd), Hypsometric (HI) and Stream Length and Gradient Index (SL) developed by Strahler (1952), Bull and McFadden (1977), Wells *et al.* (1988), Ramirez-Herrera (1998), Soewarno (1991), and Keller and Pinter (1996) (Table 1). Owing to the large size of the studied area, sampling for some morphometric indices is applied, such as proportional facet.

The sample selection was determined according to particular geomorphological criteria that provided high reliability and confidence in the representative of the morphometric data produced.

Mountain Front Sinuosity (Smf)

Smf is an index that reflects a balance between the force/power of erosion which has a tendency to cut along the curve of mountain fronts and tectonic forces that produce mountain fronts and coincide with active fault zones that reflect active tectonics. The mountain front sinuosity is a chain of mountains located on the front (Keller and Pinter, 1996). This is defined as:

$$Smf = \frac{Lmf}{Ls} \quad .... (1)$$

where:
- Lmf is a length of the bottom fronts of the mountain / valley;
- Ls is the length of mountain fronts in a straight line.

The low Smf value (1 to 1.7) is related to the active tectonics and uplift rate. If the uplift rate decreases, the erosion process will cut the mountain fronts irregularly and Smf value will increase. Smf is very easy to be calculated from topographical maps or satellite imagery with large scale and high resolution. When using a small scale, the indentation mountains irregularly shaped faces will not be properly reflected (Doorkamp, 1986).

Facet

A facet is a triangular to polyhedral shaped hill slope situated between two adjacent drainage structures within a given mountain front escarpment (Ramirez-Herrera, 1998). Tectonically, active fronts display prominent, large facets which are generated and/or maintained by recurrent faulting along the base of the escarpments (Bull, 1978, 1984). Less tectonically active mountain fronts contain fewer, smaller, and/or more internally dissected facets. Nevertheless, both small and large facets occur in tectonically active areas (Wells *et al.*, 1988). More tectonically active mountain fronts tend to be less dissected, giving a range from laterally continuous undissected escarpments to a nearly continuous front with only a few large and distinct facets with minimal internal dissection (Wells *et al.*, 1988). In this study, the proportion of faceting along mountain fronts was applied using this formula:
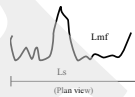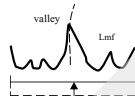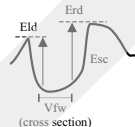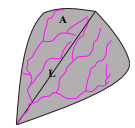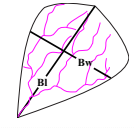
$$\frac{Lf}{Ls} \quad .... (2)$$

where:
- Lf is the cumulative length of the triangular facets on a mountain face;
- Ls is the overall length of the face of the mountains pulled straight (Wells *et al.*, 1988; Ramirez-Herrera, 1998).

The morphology of small to medium sized channels and valleys that cross mountain fronts may reflect the impact of local base-level changes due to relative uplift along active structures associated with frontal escarpments (Wells *et al.*, 1988; Ramirez-Herrera, 1998). This study uses a ratio analysis of the base width and height of

Table 1. Summary of Morphometric Parameters used in Tectonic Landform Analysis of Individual Mountain Fronts (after Ramirez-Herrera, 1998)

Morphometric Parameter	Mathematical Derivation	Mesurement Procedure	Purposes	Significance	References
Smf - Mountain Front sinuosity	$Smf = \dfrac{Lmf}{Ls}$		Reflect a balance between the tendency of stream and slope processes to produce irregular (sinuous) mountain front and vertical active tectonics that tend to produce a prominent straight front (Keller, 1986)	Low Smf reflect more active tectonic indicate direct uplift, high rate. When uplift rate decreases, erosional process will irregularly cut the mountain fronts. Smf=1·0 – most tectonic activity Smf> 1·0 – less tectonic activity	Keller&Pinter, (1996) Bull& McFadden, (1977)
Percentage faceting along mountain fronts	$\dfrac{Lf}{Ls}$		Define the proportion of a mountain front that has well defined triangular facets, using the ratio of the cumulative lengths of facets to overall mountain front length	Tectonically active fronts display prominent, large facets that are generated and/or maintained by recurrent faulting along the base of the escarpments, *i.e.* high percentage faceting	Wells *et al.*, 1988
Vf, Valley floor – valley height ratio	$Vf = \dfrac{2Vfw}{[(Eld - Esc) + (Erd - Esc)]}$		Define the ratio of the width of the valley floor to the mean height of two adjacent divides	The index reflects differences between broad-floored canyons with relatively high values of Vf, and V-shaped canyons with relatively low Vf values	Keller&Pinter, (1996) Bull& McFadden, (1977)
Rb, Bifurcation Ratio	$Rb = \dfrac{N_i}{N_{i+1}}$		Bifurcation ratio is a ratio between a number of total segments in an order with the higher order.	Higher Rb, reflects more river branching and can identify more tectonic activity.	Strahler (1952)
Dd, Drainage density	$Dd = \dfrac{L}{A}$		Drainage density (Dd) is a number which shows total length in a catchment area divided by the drainage area.	Higher drainage density means more water stored in a catchment area.	Soewarno, 1991
Bs, Drainage basin shape ratio	$Bs = \dfrac{Bl}{Bw}$		Define the planimetric shape of a basin	High Bs values = elongated basins, *i.e.* high tectonic activity; low Bs values = circular basins, *i.e.* low tectonic activity	Ramírez-Herrera, 1988
HI, Hysometric curves	$HI = \dfrac{E_{average} - E_{min}}{E_{max} - E_{min}}$		Define stadium of river	High values of HI = higher topography relatives to others; Intermediate values of HI shows incised river.	Strahler, 1952; Sarp *et al.*, 2011
SL, Stream Length - Gradient Index	$SL = \dfrac{\Delta H}{\Delta L}\, \chi\, L$		Calculate from topographic map to see tectonic activity	High index will be shown in the area with resistant litology,	Keller, 1986; Sarp *et al.*, 2011; Snow and Slingerland, 1987

the valley (Vf), the analysis of branching river/ bifurcation ratio (Rb), drainage density (Dd), and the shape of the basin watersheds (Bs) measured in 10 m contour maps to isolate anomalous patterns in a channel or valley forming attributable to tectonic activity.

Ratio of Valley Floor Width and Valley Height (Vf)

Transverse valley profiles were defined using a valley floor-valley height ratio variable. The comparison of the width of the floor of a valley with its mean height provides an index that indicates whether the stream is actively down cutting (being dominated by the influence of a base level fall at some points downstream), or is primarily eroding laterally into the adjacent hill slopes. This index can be expressed by:

$$Vf = \frac{2Vfw}{[(Eld - Esc) + (Erd - Esc)]} \quad \text{................................ (3)}$$

where:
- Vfw is the width of valley floor,
- Eld and Erd are the respective elevations of the left and right valley divides,
- Esc is the elevation of the valley floor (Bull and McFadden, 1977).

The index reflects differences between broad-floored canyons with relatively high values of Vf, and V-shaped canyons with relatively low values (Table 1). High Vf value is associated with low uplift rate. Thus, the river cuts extensively the valley floor and the shape of the valley is widened. While the low Vf value reflects a deep valley and reflects the addition of the river activity. It is associated with the uplift rate which indicates the most active tectonics.

Bifurcation Ratio Analysis (Rb)

At this stage, the morphometric characteristics of each subwatershed were analyzed as well as the type of flow pattern that developed in each subwatershed. First, the order of each subwatershed of the river must be determined. In determining the value of the order of the river, one of several methods can be used. In this study, the method by Strahler (1952) is used. Strahler method is a modification of the method of Horton (Horton's law). According to Strahler (1952) a segment that does not have branching is the first order. When two first-order segments join, it will form a second order. Two segments of second order will establish the order of three. Two orders of three will form the fourth order, and so on. Each segment can be affixed by an order with a smaller value, but will not alter or increase the order value.

According to Strahler (Ritter *et al*., 1960) morphometry characteristics of a watershed or subwatershed has three morphometric characteristics, which are linear, area, and relief. This study will examine only two types of characteristics which are linear and areal morphometry.

Linear morphometry is a morphometry characteristic which is viewed by linear watershed parameters, such as: the number of river segments, the total segment of rivers, the total length of river segments. The amount of each order river segments and the total segments in a river basin? The number of segments on each order is required to determine the value of the branching ratio (Rb). The total segment in a basin was obtained by summing up the total number of existing segments. The search for the number of segments in any order and in total was done by hand. The total length of the river is the length of the entire segment of the river, and it was calculated using the ruler aid contained in Mapinfo software.

The equation value of bifurcation ratio (Rb) is one of laws proposed by Horton (Horton's Laws). Value ratio branching or bifurcation ratio is the value ratio between the number of segments in an order and the number of segments in the next higher-order using this formula. The number of streams to an order can be determined by:

$$Rb = \frac{N_i}{N_{i+1}} \quad \text{... (4)}$$

where:
- Rb is a ratio of branching or bifurcation ratio;

- Ni is the number of segments of the river on an order to i;
- Ni + 1 is the number of segments of the river in order to i + 1.

The bifurcation ratio is a value that ignores dimensions in the calculation, for the value of this ratio is based on the number of streams in each order. Low value Rb is a watershed characteristics that experienced little interference of geological structures, and patterns of streaming is not bothered by the geological structure (Strahler, 1952). That is because the areas affected by the effects of geological structures will have to be muscular or fractures fed by river water. In other words, it represents the presence of muscular or fractures in a region.

Greater sharpness resulting in a block of rock is crushed, in other words it will have more fractures. The more fractures, the more river branches that form. Thus, it will have a higher value of Rb.

Drainage Density

Areal morphometry researched in this study is the drainage density (Dd). A current density (Dd) of a river is a number that indicates the total length of the river catchment (catchment) divided by the area of drainage. Dd is a river density index (km/km^2), Ls is the total length of all segments of a river (km), and A is the area of a watershed (km^2). The ratio is shown as:

$$Dd = \frac{L}{A}$$ .... (5)

This describes the current density of a storage capacity of surface water in a basin, such as lake, swamp, and riverbank that flows in a watershed. The higher the density level of a river, the more water can be absorbed in the body of a river. According to Soewarno (1991), river density index can be classified into four classes (Table 2). Based on this index, it can be estimated symptoms associated with the size of the river.

The lower Dd value describes the condition of the river flow that passes through rocks with loud (strong?) resistance and high infiltration

Tabel 2. Drainage Density Clasification (Soewarno, 1991)

Dd : < 0.25km/km^2	Low
Dd : 0.25 - 10 km/km^2	Medium
Dd : 10 - 25 km/km^2	High
Dd : > 25 km/km^2	Higher

capacity. Thus, the distance between tenuous flow and hydrological slow reaction. Dd high value describes the condition of river channel that passes through rocks with low resistance and low infiltration capacity, so the distance between the meeting flow, watershed mutilated. It provides a relatively faster reaction to the influx of rainfall.

If the Dd value is very high, the river will flow past the rock watertight. This situation indicates that the rain water flow will be greater when compared with the low pass Dd large rock permeability.

Drainage Basin Shape (Bs)

The typical basin of a tectonically active mountain range is elongate, and basin shapes become progressively more circular with time after cessation of mountain uplift (Bull and McFadden, 1977). Thus, the planimetric shape of a basin may be described by an elongation ratio of the diameter of a circle with the same area as the basin to the distance between the two most distant points in the basin (Cannon, 1976). Here the planimetric shape of a basin is described by an elongation ratio Bs that can be expressed as:

$$Bs = \frac{Bl}{Bw}$$ .... (6)

where:
- Bl is the length of the basin, measured from its mouth to the most distant drainage divide,
- Bw is the width of the basin measured across the short axis (Table 1).

The index reflects differences between elongated basins with high values of Bs and more circular basins with low values. Drainage basin widths are much narrower near the mountain front in tectonically active areas where the energy

of the stream has been directed primarily to down cutting. By contrast, a lack of continuing rapid uplift permits widening of the basin upstream from the mountain front.

Hypsometric Curves (HI)

On measuring hypsometric curves (Figure 2), location points were plotted in one subwatershed on a topography map. Then the area was determined from selecting elevation (a), the total area of that subwatershed (A), selecting elevation (h) and the highest elevation on that subwatershed (H) on every point in that location. This measuring used ArcView 3.3. Then the total proportion of subwatershed area (a/A) and proportion of total subwatershed elevation (h/H) were computed, and every point was plotted into a hypsometric diagram. The next step was comparing it with the Strahler curve to know the river stadium (Strahler, 1952). The formula is presented as:

$$HI = \frac{E_{average} - E_{min}}{E_{max} - E_{min}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(7)}$$

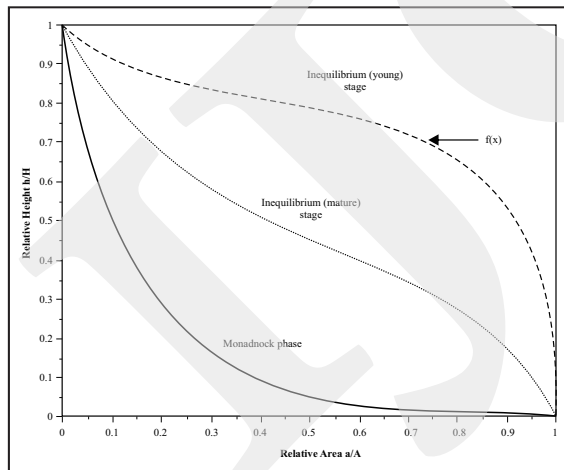

Figure 2. Hypsometric curves for three watersheds (Strahler, 1952).

Stream Length Gradien Index (SL)

Stream Length Gradien Index (SL; Figure 3) is calculated from a topographic map according to this formula:

$$SL = \frac{\Delta H}{\Delta L} \chi L \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(8)}$$

where:
- SL= Stream length gradient index,
- ΔH = Elevation difference from the calculated point,
- ΔL = River length up to the calculated point,
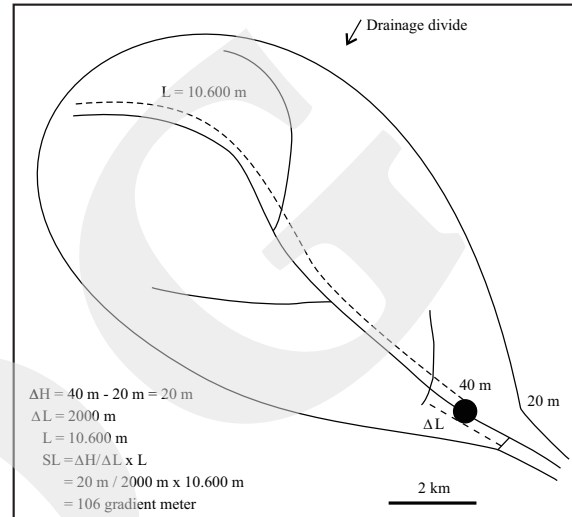- L = Total length from the upper course until the point calculated.

Figure 3. Calculated method of SL (Keller and Pinter, 1996).

SL index is very sensitive to changes of channel slopes which can be related to tectonic in surrounding High SL region, and low SL values can be related to tectonic which is recently active. For instance along linear valley which is caused by a strike slip fault would have low value of SL because of smashed along the valley (Snow and Slingerland, 1987).

Statistical Test Analysis

Hypothesizing two independent samples is to test the generalizability average of two data samples that are not correlated (Sugiyono, 1999). In this study, statistical tests used were normality test and different test (t-test). The normality test is used as a condition of the parametric test. If the data are normal, the parametric test can be done.

Normality Test

Normality test is a form of testing on the normality of data distribution, in order to determine

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whether a variable is normal or not. Normal here means having a normal distribution of data. Normal or not, it is based on the standard normal distribution of the data with the same mean and standard deviation . Thus, a normal test basically do a comparison between the data we have the normal distribution of data that has mean and standard deviation of the same with our data. With such data, the profile data is considered to be the representative of the population. To test the normal data, SPSS software can also be used, using the Kolmogorov-Smirnov test for normality.

Kolmogorov-Smirnov test is a test of normality that is widely used, particularly after many statistic programmes are outstanding. The advantages of this test are simple and do not give rise to differences in perception between one and other observers, which often occur in normality test using charts. The basic concept of Kolmogorov-Smirnov normality test is to compare the distribution of data with a standard normal distribution. Applying the Kolmogorov-Smirnov test is if the significance is below 0.05. It means the data to be tested have significant differences with normal data standard, meaning the data is not normal. Otherwise, if the significance is above 0.05, it means the data to be tested do not have significant difference with normal data standard, meaning the data is normal.

Test different (t-test)

This test is done to see the comparison between the sample-free, whether significantly different or the same. There are two t-test formulas that can be used to test the hypothesis that two independent samples are comparative to separated variance and polled variance.

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\dfrac{S_1^2}{n_1} + \dfrac{S_2^2}{n_2}}}$$

(Separated Variance)

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\dfrac{(n_1-1)S_1^2 + (n_2-2)S_2^2}{n_1 + n_2 - 2}} \sqrt{\dfrac{1}{n_1} + \dfrac{2}{n_2}}}$$

(Polled Variance)

Based on the formula above, the instructions were followed in selecting the t-test formula.

- If $n_1 = n_2$ and homogeneous variance $\sigma_1 = \sigma_2$, it can use t-test formula polled separated and variance. To find used t table df $= n_1 + n_2 - 2$.
- If $n_1 \neq n_2$, homogeneous variance $\sigma_1 = \sigma_2$ can use t-test with polled variance. To find used t table df $= n_1 + n_2 - 2$.
- If $n_1 = n_2$, the variance is not homogeneous $\sigma_1 \neq \sigma_2$ can be separated and polled variance. To find used t table df $= n_1 - 1$ or dk $= n_2 - 2$.
- If $n_1 \neq n_2$, the variance is not homogeneous $\sigma_1 \neq \sigma_2$ can be separated variance formula.

To know the difference between the t table used df $= n_1 - 1$ and dk $= n_2 - 1$, divided by 2 and then added with t minim price.

If t <t table then accept Ho which means not significantly different or not there is an average difference between the two samples such independent, but if t $\geq$ t table then reject Ho which means significantly different, or there is an average difference between the two independent samples.

Results and Analysis

Mountain Front Sinuosity (Smf)

Smf calculations based on the separation of the two blocks by the Sumatra Fault, into southwestern (SW) and northeastern (NE) blocks (Figure 4) which determine the calculation of Smf in the studied area show that the average value of the southwestern block is 1.595, in the area along the Sumatra Fault is 1.537, whereas in the northeastern block it is 1.699. This condition describes that the uplift is directly and closely related to the tectonic activeness (Doornkamp, 1986).

The lower Smf values are represented by the NE Block, indicating the uplift intensively occurs
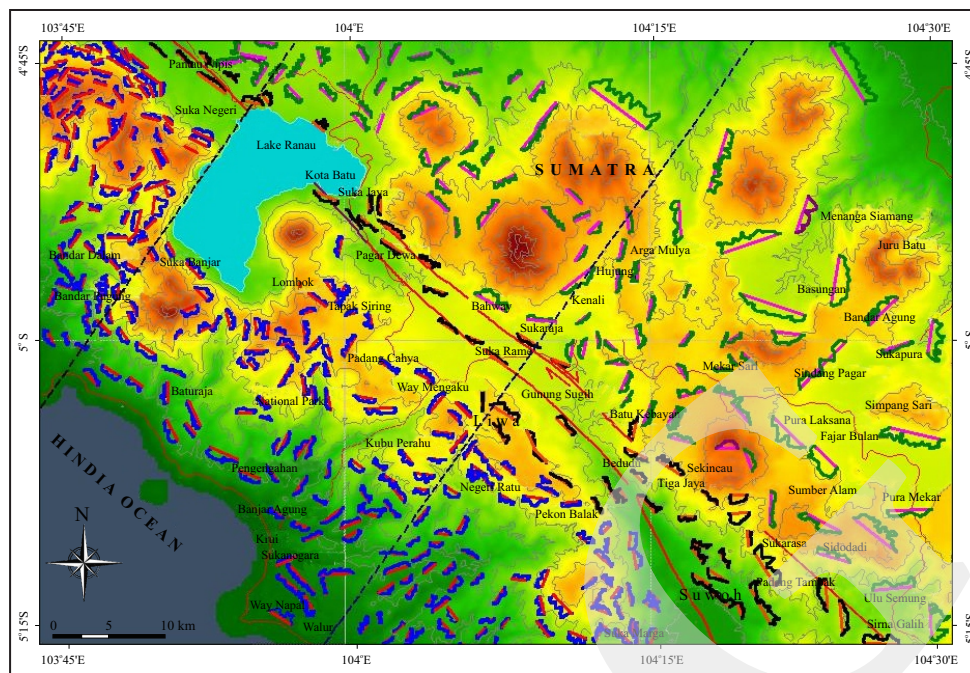
Figure 4. Three evaluation zones of Smf (green is NE Block, black is along the fault, and blue is SW Block; red continuous line is Sumatra Fault).

on this block. While values from the three zones obtain Smf A (1.438) which is less than Smf B (1.525) and is less than Smf C (1.614). It shows that it is more active to the northwest (A).

Facet Percentages (Lf/Ls)

The results of the mountainous front which has facets are shown by the value of the ratio of the cumulative length of triangular facets (Lf) with the long straight of the whole face of the mountains (Ls). The average value of the Lf / Ls for the NE Block is 0.58, while the average value for the NE Block is 0.42. The average value for Lf / Ls in the fault zone is 0.51. This indicates that the value of Lf / Ls is higher and more active than the smaller ones. Here, it is clear that this fault zone has a higher value. The SW Block has a greater value than the value of the NE Block. This means the tectonic works on NE Block are relatively more active than the SW Block, which is reflected by more facets on mountain fronts in the NE Block.

Width Floor and Valley Height Ratio (Vf)

The calculation shows that the Vf value ratio on the Sumatra Fault lines (Figure 5) has an average of 0.36, which reflects the direct uplift of the active mountain fronts (Bull, 2007). The average Vf value of SW Block is 0.364, while the NE Block is 0.531. In the northeastern block, the Vf value is greater than the southwestern block. It shows that the tectonic blocks of southwestern part obtain greater sharpness than the northeastern one. Thus, it can be deduced that the southwestern block found more debris on the mountain fronts (Bull, 2007). Based on the calculation, the average value of the NE Block is larger than the SW Block, which shows that the SW Block is more active, but the type of rock in the NE Block is more resistant.

The calculation from the three zones shows that zone A (0.4911) is less than zone B (0.5349) and zone C (0.5607), showing that the tectonic activity is relatively higher in zone A rather than in the other two zones.

Bifurcation Analysis (Rb), Drainage Density (Dd), and Drainage Basin Shape (Bs)

The studied area are divided into four watershed patterns, *i.e.* subdendritic-, dendritic-, radial-, and parallel stream patterns that show landform in the rock type which have the same
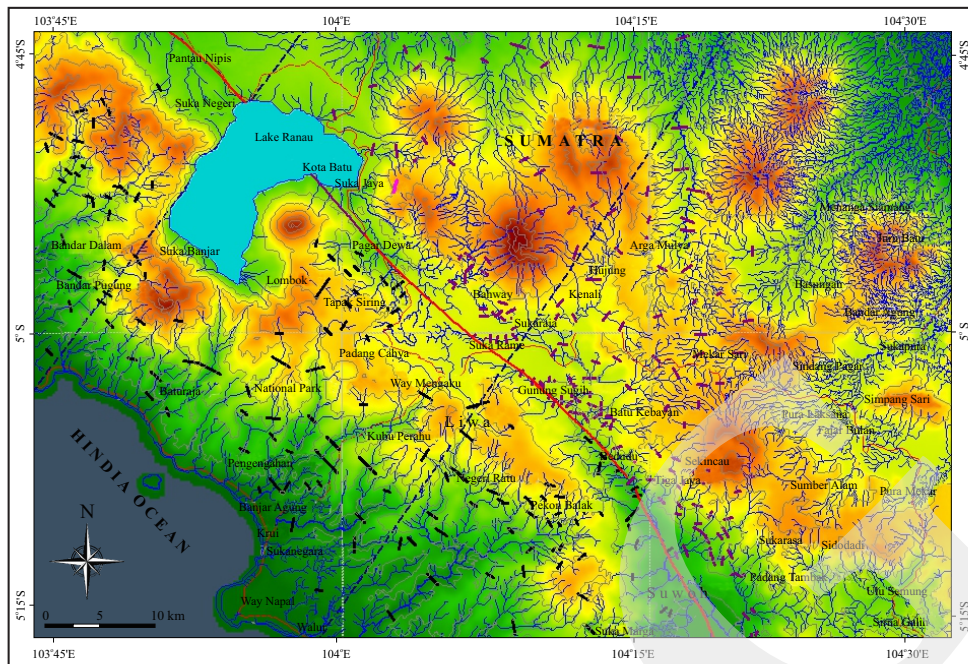
Figure 5. Vf calculation map.

relative hardness and normally exists in the area of an active geological structure (Van Zuidam, 1985). The studied area is composed of the same rock that is entered into the tuff of Ranau Formation developing Sumatra Fault passing through the researched area.

Rb and Dd calculations were done for each subwatershed, and subbasins in both SW and NE Blocks will be compared. The boundaries of subbasins are made on the same rock formations, namely the Ranau Formation Tuff. The SW Block consists of 22 subbasins, while the NE Block has more than that (Figure 6). The values of more than 5 (violet colour) in the SW Block are located on Seblat Formation, which has Tertiary age and is older than the Ranau tuff. While values of more than 5 in the NE Block are located on volcanic breccia/tuff which is younger than the Ranau tuff.

The calculation shows that the average value of Rb of NE Block (6.4) is relatively larger than SE Block (4.9). But the averaged Dd value of NE Block (0.202) is smaller than the average Dd value of SW Block (0.264) (Figure 7). The greater Rb value indicates that NE Block has undergone stronger tectonic forces than SE Block. But the Dd value of NE Block which is smaller

than the SW Block, indicate that greater tectonics are experienced by SW Block. Because of these differences, it is necessary to analyze the other subzones, *i.e.* the ratio of the river drainage basin shape (Drainage Basin Shape Ratio/Bs).

Based on the three zones, the same as Smf and Vf, values of Rb are also lesser in the northwest (zone A), which indicate that tectonic activity was prior to the southeast.

The calculation of the drainage basin shape ratio (Drainage Basin Shape Ratio/Bs; Figure 8), shows that the SW Block has a greater average Bs value (1.9) than the average Bs value owned by the NE Block (1.8). Thus, it can be concluded that level of activity in the southwestern block is greater than in the northeastern block.

In general, statistical test analysis results the average value of the two blocks is not much different, whereas the calculated T value is smaller than T-reference which suggests that the value of the Smf in both blocks are not significantly different.

Different test results show that calculated T value is bigger than T-reference, then Ho rejected. It means that by the significant level of 95%, it can be concluded there is a real difference between both variables of the southwestern block and northeastern block.
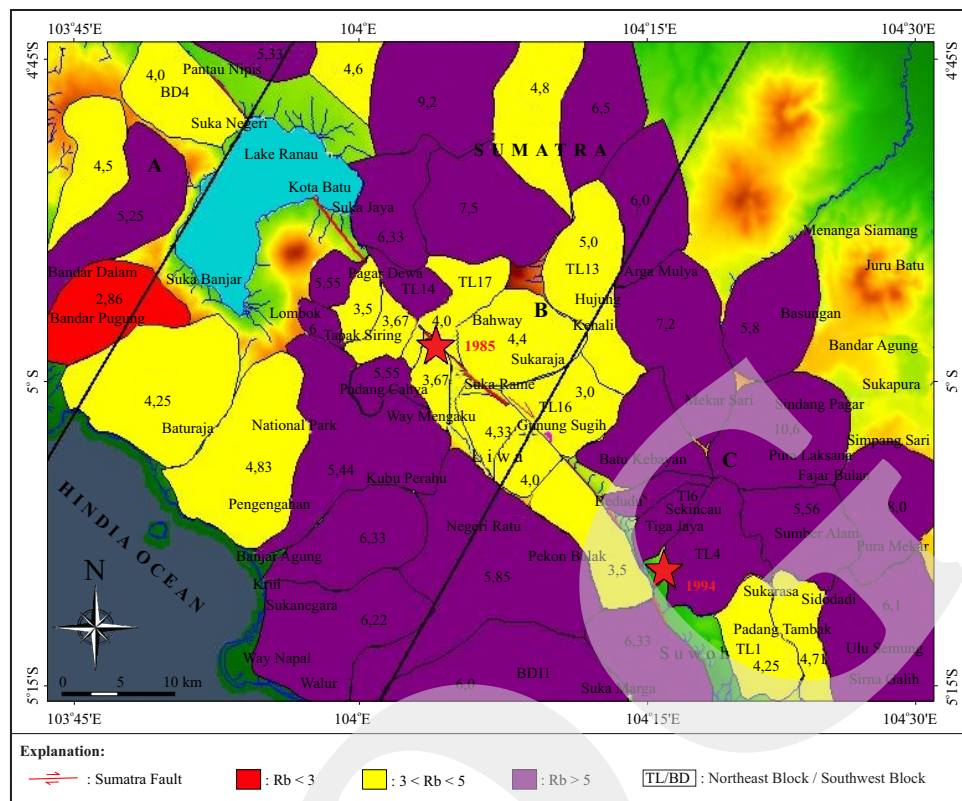
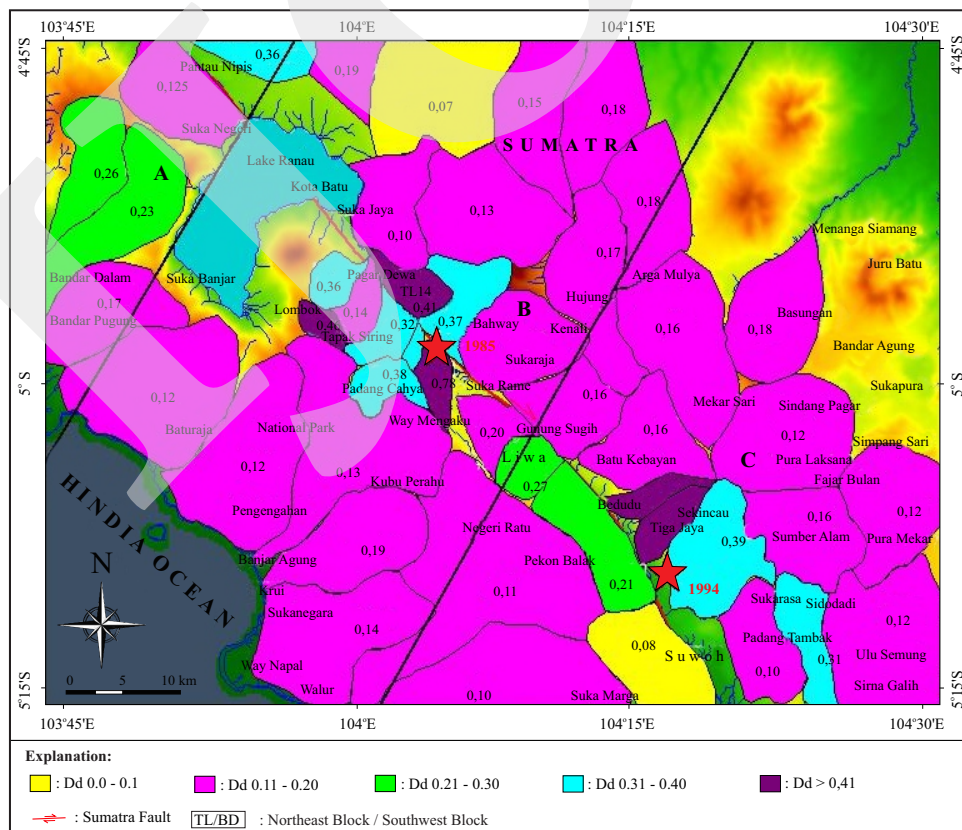Figure 6. A map of subwatershed and Bifurcation Ratio.

Figure 7. A map of subwatershed and Drainage Density.

Statistically, the correlation test result shows that, in general, both blocks have weak to strong correlations (Table 3).

Hypsometry curve on zone A is dominated by the young stadium, which indicates the "V" valley shape caused by the vertical erosion is more dominant than the horizontal erosion (Figure 9).

While zone B and C are dominated by the mature stadium, which indicates morphology relief and the "U" shape of the valley represent the balance of erosion process. This shape starts to show meandering (Strahler, 1952; Moglen and Bras, 1995; Willgoose and Hancock, 1998; Huang and Niemann, 2006).
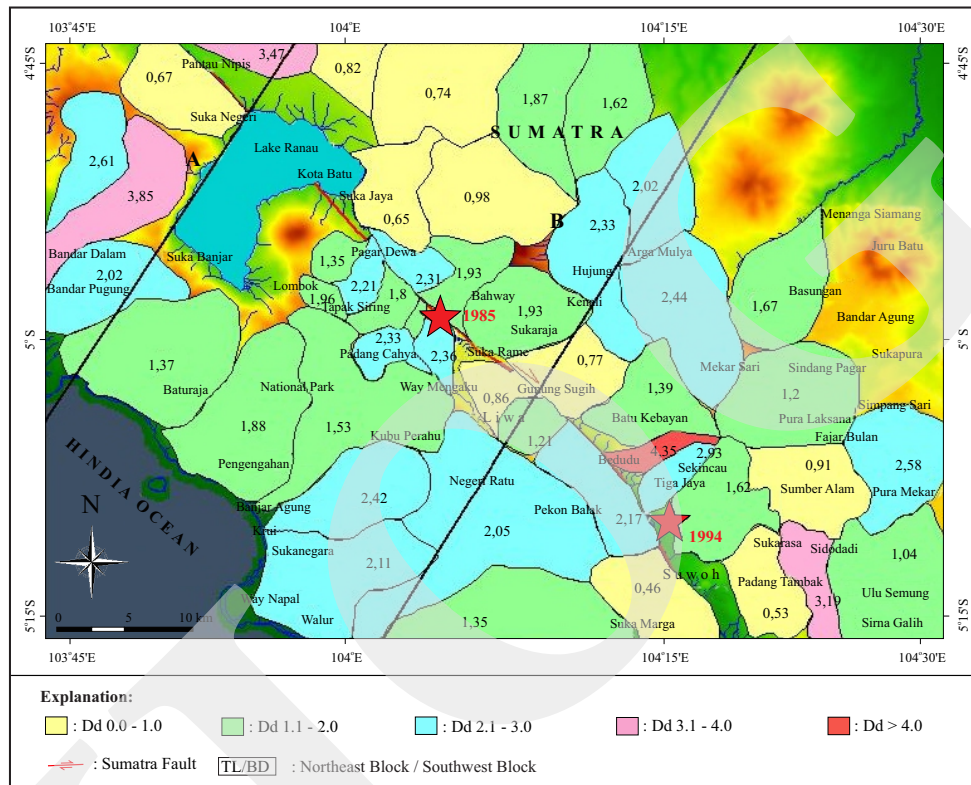

Figure 8. A map of subwatershed and Basin Shape.

Table 3. Summary of Statistical Result from Morphometry Analysis

Variable	Average value	T-test	Correlation Test	Statistical Interpretation	Geological Interpretation
Smf	SW= 1,595 NE = 1,699	T-alc.=1,517 < T-table=2,25	R=0.21	Not significantly different, weak correlation	Tectonically active, SW more active than NE
Lf/Ls	SW= 0,58 NE= 0,42	T-calc. =3,205 >T-table= 2.319	R=0,54	Not significantly different, strong correlation	Tectonics working on both blocks are relatively similar
Vf	SW=0,364 NE = 0,531	T-calc.=5,15 > T-table=2,254	R=0,02	Significantly different, very weak correlation	Lithology type in the NE Block more resistant, while in the SW Block softer
Rb	SW= 4,9 NE= 6,4	T-calc.=2,938 > T-table=2,315	R=0,698	Not significantly different, strong correlation	NE more active than SW
Dd	SW= 0,202 NE= 0,264	T-calc. =1,346 <T- table=2,315	R=0, 149	Not significantly different, weak correlation	NE more active than SW
Bs	SW= 1,92 NE= 1,791	T-calc.=0,499 < T-table=2,315	R=0, 361	Not significantly different, correlation	SW more active than NE

Stream length gradient indexes along the Sumatra Fault are close to zero, following the distribution of Ranau tuff in Liwa, which is thinner and narrower on zone A (Figure 10). It is wider on zone B, and it is reducing on zone

C. The fluctuation of SL values is shown on the same rocks which have the same resistance as the indicator of active tectonics (Keller, 1986).

Calculation data presented on Table 4 indicate that the structure analysis within zone. A tends to
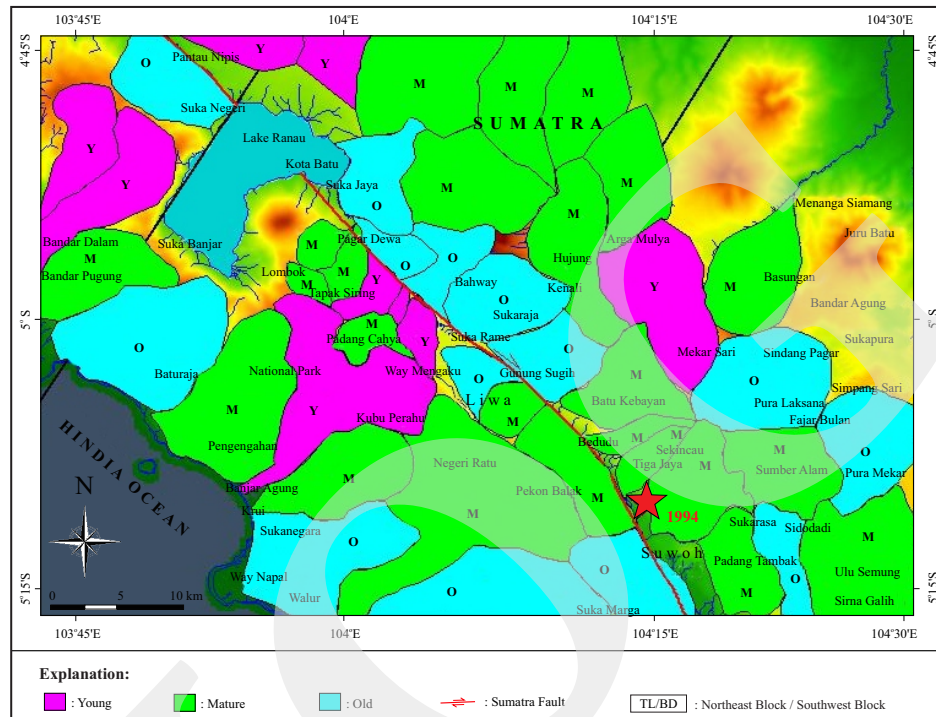

Figure 9. Map of Hysometric Curves show by letters Y (Young), M (Mature) and O (Old).
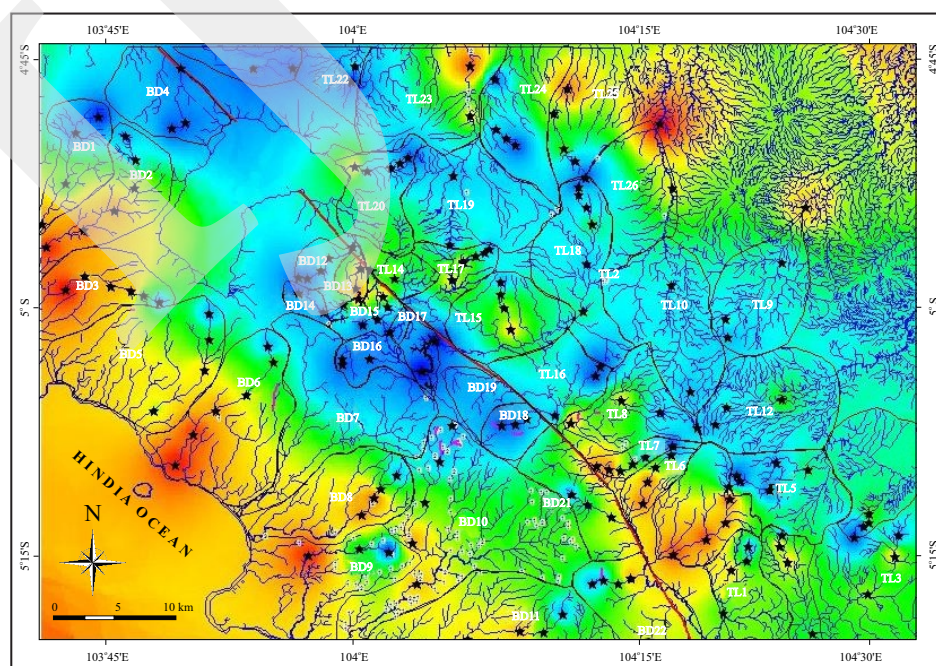

Figure 10. Map of Stream length-Gradient Index.

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Table 4. Summary of Statistical Result from Morphometry Analysis

No.	Parameter	Northwest Zone (A)	Central Zone (B)	Southeast Zone (C)	Evaluation
1	Smf	1.438	1.525	1.614	Smf A < Smf B < Smf C The average Smf values of the three zones show active tectonics. Smaller towards northwest.
2	Vf	0.4911	0.5349	0.5607	Vf A < Vf B < Vf C The average values of Vf of zone A is the smallest, which is the active.
3	Rb	4.39	5.617	5.9215	Rb A < Rb B < Rb C Rb values are larger towards southeast, indicate tectonic active started from the southeast.
4	Dd	0.2284	0.2365	0. 185	Dd A < Dd B > Dd C The average values of Dd is bigger on zone B, show that the tectonic work on B more stronger.
5	Bs	2.524	1.538	1.677	Bs A > Bs B < Bs C The biggest of basin shape is the stronger tectonic activity.
6	HI	Y=3; M=1; O=1 (young)	Y=4; M=12; O=7 (Young- mature-Old)	Y=1; M =11; O= 6 (mature-old)	Young stage is found on zone A, while on zone B and C found mature stages. It shows that tectonic activity started on B and C than zone A. The southeastern zone has tectonic process earlier, and compression still accumulated on zone A.
7	SL	Narrow	Wider	Narrow	Zero values is along the Sumatra Fault, and follow the same lithology distribution.
8	River lineaments	NW-SE	NW-SE; W-E; few NE-SW	W-E; NE-SW	Zone A is younger and still follow the main trend of Sumatra Fault which is NW-SE, while to the southeast more develop.
9	Structures lineaments	NNE-SSW	NE-SW	N-S; NE-SW	Trend of structure shows perpendicular to the river lineaments, representing the direction of compression. Zone A shows the main compression of Sunda subduction which is NNE-SSW, while more to the southeast change to be more NE-SW (middle), and southeastern has both combination.

have the trend of north northeast - south southwest (NNE - SSW), following the main movement of the Sunda subduction. This trend is perpendicular to the trend of river segment lineaments which is dominated by Sumatra Fault trend which is northwest - southeast (NE - SW). While zone B has a general trend of northeast - southwest (NE - SW), and zone C has the combination of zones A and B.

Conclusions

Geomorphic assessment could be the best tool to analyze the tectonic activity in a region using the morphometry analysis, and it is tested by a statistical analysis.

The calculation of Smf in the studied area shows an average values of 1.595 in southwestern (SW) block, 1.537 in the area along the Sumatra Fault (SF), and 1.699 in the northeastern (NE) block. This tends to indicate that the uplift is directly and closely related to the activeness of tectonics. The results of the average value of facets (Lf / Ls) for the SW Block is 0.58, while the NE block is 0.42, and the SF is 0.51. It shows that the SW Block has a greater value than in other places, which means the tectonic working on SW Block are relatively more active than in the NE Block.

The average Vf value of SW Block is 0.6, while the NE Block is 0.9. It shows that the tectonic block of SW obtains greater tectonic applied than the NE Block. Thus, it can be deduced that the SW Block found more debris on the mountain fronts.

The average Rb value of SW Block is 6.4 which is relatively larger than the SW Block which is 4.9.

But the average Dd value of NE Block (0.202) is smaller than the SW Block (0.264). Drainage Basin Shape Ratio (Bs) shows that the SW Block has an average value of 1.92, while the NE Block is 1.79. Thus, it can be concluded that the level of activity in the southwestern block is greater than in the northeastern block.

Statistically test results show that both variables in southwestern and northeastern blocks are not significantly different, but they have weak to strong correlation. It means that tectonic works in both blocks are relatively similar. But the lithological type in NE Block is more resistant, while in the SW Block it is softer. The southwestern block is composed of Ranau tuff which has Plio-Pleistocene age and Pliocene volcanics consisting of andesite and basalt. On the other hand, the northeastern block is composed of Ranau tuff and Pleistocene volcanic breccia and tuff.

The tectonic changes obviously observed in the studied area are divided into three zones: northwest (A), middle (B), and southeast zones (C). Based on a morphometry analysis, it is obtained that tectonic activity started from the southeast towards the northwest. Based on the hypsometric curves, young stages are shown on northwest zone (A), while mature to old stages of hypsometric curves are shown on zone B and C. It means that stress accumulation occurs in the northeast and decreases to the southeast.

Stream length gradient index is close to zero along the Sumatra Fault, following the Ranau tuff distribution, thin and narrow at the northwest, wider in the middle, and decreases on the southeast. It shows that the tectonic activity is relatively young in the northwest, and much older to the southeast.

REFERENCES

Bull, W. and McFadden, L., 1977. *Tectonic geomorphology north and south of the Garlock fault*, California. Proceedings Vol. of 8th Annual Geomorph. Symp. (Edited by Doering, D.O.) State University of New York at Binghamton, Binghamton, NY. 1977, p.11-138.

Bull, W.B., 1978. Geomorphic tectonic activity classesof the Sout Front of the San Gabriel Mountains, *Report 14-08-001-G-394*, Office of Earthquakes, Volcanoes and Engineering, Menlo Park, CA.

Bull, W.B., 1984. Tectonic Geomorphology. J*ournal of Geological Education 32,* p.310-324. DOI: 10.5408/0022-1368-32.5.310

Bull, W.B., 2007. *Tectonic Geomorphology of Mountains: A New Approach to Paleoseismology.* Wiley, ISBN: 978-1-4051-5479-6. 328pp.

Dini, Bela, Hartono, T., Mulyono, A., Sutardi, N., Baidilah, Rusmana dan Rukmana, I., 2003. *Pengembangan Basis Data Bencana Kebumian (Geologi) Daerah Lampung*, LIPI, Jakarta.

Doornkamp, J.C., 1986. Geomorphological Approaches to the Study of Neotectonics. *Journal of the Geological Society*, Vol. 143, p.335-342, London. DOI: 10.1144/gsjgs.143.2.0335

Horton, R.E., 1945. Erosional development of streams and their drainage basins: hydro-physical approach to quantitative morphology, *Geological Society of America Bulletin* 56 (3), p.275-370. DOI: 10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2

Huang, X.J. and Niemann, J.D. 2006. Modelling the potential impacts of groundwater hydrology on long-term drainage basin evolution, *Earth Surface Processes and Landforms* 31 (2006), p.1802-1823. DOI: 10.1002/esp.1369

Katili, J.A. and Hehuwat, F., 1967. *On the occurrence of Large Trunscurrent Faults in Sumatra*, Indonesia. Geotectonics of Indonesia.

Keller, E., 1986. *Investigation of Active Tectonics: Use of Surficial Earth Processes, Active Tectonics Studies in Geophysics.* National Academy Press, Washington, DC.

Keller E. and Pinter N. 1996. *Active tectonics: Earthquake, uplift, and landscape.* Prentice Hall, Upper Saddle River, N.J., 337pp.

Natawidjaja, D.H. and Kusumadharma, S., 1993. Karakteristik gerakan tanah dan sesar aktif untuk pengembangan daerah Liwa, Kabupaten Lampung Barat. *Prosiding pertemuan ilmiah tahunan ke 22 Ikatan Ahli Geologi Indonesia*, di Bandung.

Natawidjaja, D.H., 2002. *Neotectonics of the Sumatran Fault and Paleogeodesy of the Sumatran Subduction Zone.* Doctoral thesis, 289pp.

Natawidjaja, D.H. and Triyoso, W., 2007. The Sumatra Fault Zone: from source to hazard. *Journal of Earthquake and Tsunami*, 1(1), p.21-47. DOI: 10.1142/S1793431107000031

Ramirez-Herrera, M.T., 1998. Geomorphic Assessment of Active Tectonics in the Acambay Graben, Mexican Volcanic Belt. *Earth Surface Process and Landforms,* 23, p.317-332. DOI: 10.1002/(SICI)1096-9837(199804)23:4<317::AID-ESP845>3.0.CO;2-V

Ritter, Dale F., Kochel, R., Craig, and Miller, Jerry R., 1995. Process Geomorphology 3d ed. Dubuque, Iowa: W.C. Brown Publishing.

Sarp, G., Gecen, R., Toprak, V., Duzgun, S., 2011. *Morphotectonic properties of Yenicaga basin area in Turkey.* https://www.researchgate.net/publication/260187388_MORPHOTECTONIC_PROPERTIES_OF_YENICAGA_BASIN_AREA_IN_TURKEY

Sieh, K. and Natawidjaja, D., 2000. Neotectonics of the Sumatran fault, Indonesia. *Journal of Geophysical Research,* 105, p.28,295-28,326. DOI: 10.1029/2000JB900120

Soehaimi, A. and Kertapati, E., 1995. Seismotectonics of the Sunda Straits and Earthquake Risk Evaluation, *Journal GSDM*, 49 (V), p.25-32.

Snow, R.S., Slingerland, R.L., 1987. Mathematical modeling of graded river profiles. J. Geol. 95, p.15-33.

Soewarno, 1991. *Hidrologi Pengukuran dan Pengolahan Data Aliran Sungai (Hidrometri),* Nova, Bandung.

Stewart, I.S., dan Hancock, P.L., 1994, *Neotectonics in P. L. Hancock (Ed.), Continental Deformation,* Pergamon Press, Oxford, p.370-409.

Strahler, A.N., 1952. Hypsometric (area-altitude) analysis of erosional topology. *Geological Society of America Bulletin,* 63 (11), p.1117-1142. DOI: 10.1130/0016-7606(1952)63[1117:HAAOET]2.0.CO;2

Sugiyono, 1999. *Statistika untuk penelitian*, CV Alvabeta, Bandung.

Van Zuidam, R.A., 1985. *Aerial photo-interpretation in terrain analysis and geomorphological mapping.* Smith Publishers/ITC, The Hague. DOI: 10.2307/215100

Wells, S.G., Bullard, T.F., Menges, C.M., Drake, P.G., Karas, P.A., Kelson, K.I., Ritter, J.B., and Wesling, J.R., 1988. Regional variations in tectonic geomorphology along a segmented convergent plate boundary, Pacific coast of Costa Rica, *Geomorphology*, 1, p.239-265. DOI: 10.1016/0169-555X(88)90016-5

Willgoose and Hancock, 1998. Revisiting the hypsometric curve as an indicator of form and process in transport-limited catchment, *Earth Surface Processes and Landforms* 23, p.611-623.