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# Geomorphology and structural geology characterization of landslide prone area in Riau-West of Sumatra Highway

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**Abstract.** Research areas are prone to landslides hazard. Detail location is in the Tanjung Balik area, Pangkalan Koto Baru Sub District, Lima Puluh Kota District, West Sumatra Province. Located is along the Riau – West of Sumatra Province Highway throughout kilometers 10-15. Coordinate are between 00°08'40"-0°11'20"N and 100°45'20"-100°47'00"E. The research objectives determine the geomorphological conditions, drainage patterns, and structural geology in the research area. The methods are geological survey and geomorphological analysis. The results of the analysis concluded that the geomorphology of the research area was classified into two, namely Structural Steep Hills Geomorphology Unit (S2) and Denudation Slightly Steep Hill Geomorphology Unit (D3). The Structural Steep Hills Geomorphology Unit (S2) is in the Southern region of the research area with distribution percentage around 27%, while the Denudation (S2) dominates in the North, West, East and slightly in the South with a distribution percentage around 73%. Drainage pattern is classified as sub-dendritic types. Geological analysis of structures from joint readings shows the main stresses that have relatively north-south direction.

## 1. Introduction

### 1.1. Location

Location is administratively in the Tanjung Balik Area, Pangkalan Koto Baru Sub District, Lima Puluh Kota District, West of Sumatra Province. The geographical position of the research area is located between 0°08'40"N - 0°11'20"N and 100°45'20" E - 100°47'00" E. Elevation of research area are based on a topographical, the lowest and the highest elevation are 80 meters and 345m respectively above sea level. This research purposes to figure out the geomorphology, drainage pattern, and structural geology.

Physical characteristics of the region could be identified through by topography[1], geology[2], regional morphology[3], soil type[4], climate[5], hydrology[6][7], and so on[8]. The Lima Puluh Kota District has a topographic variation, where more than half the area contains mountainous topography (with slopes of more than 40%), which has percentage is around 56.3%. The slope could be utilized as a cultivation area is below 40%, which coverage is around 46.7% of the district area. The topography of Lima Puluh Kota District has varies between flat, wavy and hilly[9][10][11][12][13][14][15]. In this area there are three inactive volcanoes[16][17][18][19][20]. Regarding the location and height of each

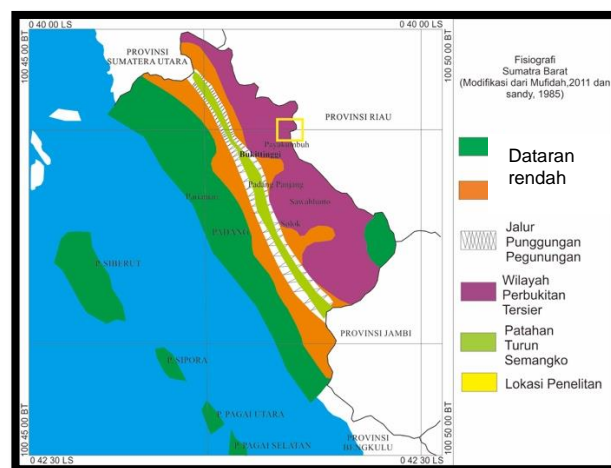


mountain in more detail can be seen in Table 1, which shows the classification of slopes and topography based on the Lima Puluh Kota Spatial Plan Revision in 2010.

**Table 1.** Slope and topography classification in 50 districts based on 50 city spatial plan revision in 2010

No	Topography	Slope	Class Slope	Relative difference of elevation between the highest and lowest point (m)	Area
					Ha
1	Flat	0 – 2%	A	1	14.924
2	Wavy	2 – 5%	B	1 - 10	12.031
3	Corrugated	5 – 8%	C	1 - 10	6.007
4	Hilly	8 – 15%	D	10 - 50	26.289
5	Hilly	15 – 25%	E	10 – 50	9.195
6	Hilly	25 – 40%	F	50 – 300	77.970
7	Mountainous	40%	G	>300	189.014
<b>Total</b>					<b>335.430</b>

The research area is included in the tertiary territory, which is generally composed of steep hills, wavy hills, highlands and flat lands scattered in several places[9][21], shown in Figure 1.



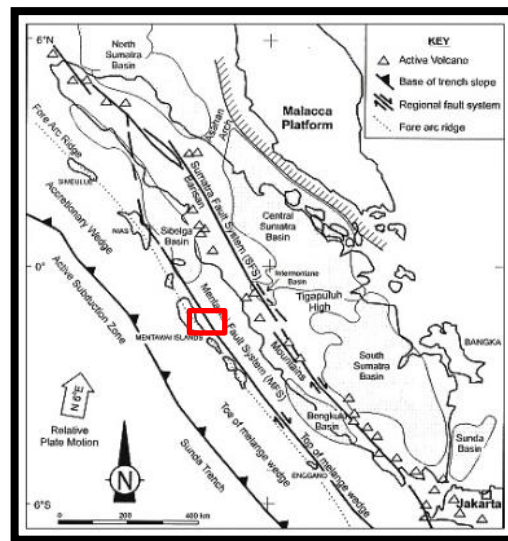
**Figure 1.** Physiographic map of West of Sumatra which shows the research area marked in yellow boxes.

### 1.2. Regional Physiography

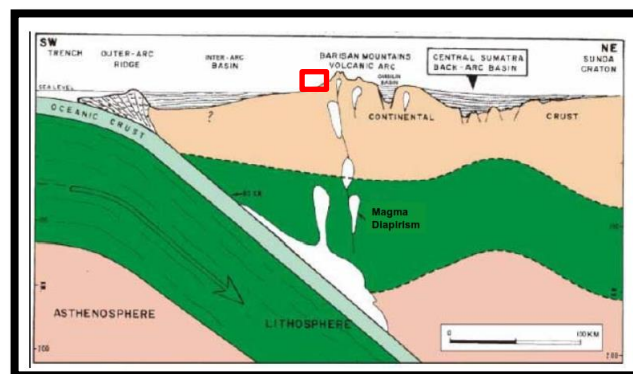
Sumatra Island physiographical extensions are northwest to south orientation, which is influenced by the Eurasian continent plate at western boundary of Sundaland as precisely. The position of the Sumatra Island is adjacent to the boundary between the Indian-Australian oceanic plate and Sundaland. Subduction zone of the two plates are marked by the active Sunda Mountains system and extends from Burma in the north to south, where the Australian plate collides with the eastern part of Indonesia[22][23]. Subduction between the Indian-Australian plate and Sundaland forms a sloping convergent pattern. The tilt movement is the resultant force, which is a downward movement and horizontal movement. The downward movement was accommodated by subduction of the Indian-Australian Ocean plate under Sundaland. While the horizontal movement is reflected in the shear fault patterns that form a series of structures such as *dextral wrenching* within Sundaland. The strike slip fault structure series eventually formed a large Sumatran Fault known as the Semangko Strike Slip Fault. It

produces a weak zone that allows the movement of blocks and landslides[6][24][25]. The regional Tectonic Framework of the research area is shown in Figure 2.

Strike Slip Semangko Fault movement also produced weak zone that allows a magma exit from volcano and range of Barisan Mountains. The position of Semangko Fault is right on the line of the Mountain Volcanic-Arc, which is proven by Wrench Faulting of the mountains. In the *back-arc basin* area, it is influenced by tensional with the direction of force perpendicular to the subduction zone. This tensional regime is caused by the presence of heat flow below the surface. The compression force of Wrench dextral trends are parallel to the plate boundary and strongly to influences the conventional regime in the back-arc basin and to generate structures. It is aligned parallel to the plate boundaries[26][27]. Sumatra Island cross section shows in Figure 3 from east to west direction.



**Figure 2.** Regional tectonic framework of the research area is marked in a red colored box.



**Figure 3.** Cross section intersects Sumatra Island in the west-east directions, the red box shows the research area.

The Limapuluh Kota District is included as part of the thirty tertiary hill areas and gets the influence of the movement of the Semangko Fault system, where rock deformation and mineralization of various types of rocks could be found. Based on the results of previous investigations, mineralization was found in old rocks (Permian – Carbon age) and Tertiary[23][7].

## 2. Method

The geomorphology is defined as a study that describes the shape of land, the process and the relationship. The spatial are landform and the process in the arrangement. The formation of the landscape is the result of the geomorphological process caused by the endogenic and exogenic forces.

The landscape has varied shapes and classified based on certain factors such as process, phase, and the type of lithology as well as the influence of geological or tectonic structures that work [28]. The classification of landscapes (Table 2) and (Table 3) into geomorphological units based on several factors through five approaches are: morphography is an aspect that describes the morphology of an area such as terrain, hills or mountains. Morphometry is the value of an area geomorphology aspect, such as slope, elevation, slope length and roughness relief can be seen in Table 4. Passive morphostructure aspects are observed the lithology type and rock structure associated with the erosion process, such as cuesta, hogback and dome. Active morphostructure is the aspect that examines the activity of endogenic processes such as volcanism, fractures and creases, such as volcanoes, anticline formed mountain, fault slopes. Morphodynamics are aspects that describe exogenic processes associated with wind, water or ice motion, such as sand dune, fluvial plain, sedimentation or desert [2][3].

**Table 2.** Landscape unit classification based on their heights

Relief Unit	Angle Slope (%)	High (m)
Flat or nearly flat	0-2	<5
Corrugated / sloping ramps	3- 7	5-50
Wavy	8 - 13	51-75
Hilly Wavy	14-20	76-200
Hilly sharp steep	21 -	55200-500
Mountains sharp cuts	55-140500	1000
Very steep	Mountains>140>	1000

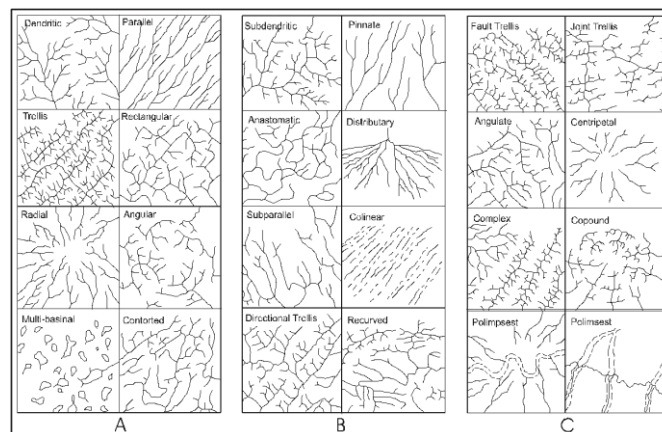
**Table 3.** Classification of Landscape Unit

Landform	Symbol	Color
Structure Formation	S	Purple
Origin of volcano formation	V	Red
Denudation Formation	D	Brown
Sea origin Formation	M	Navy
River origin / fluvial Formation	F	Green
Wind Formation	A	Yellow
Karst Formation	K	Orange
Glacial Origin Formation	G	Blue Bright

**Table 4.** Classification Structural Landform

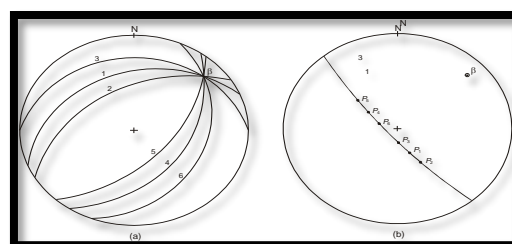
Geomorphological Processes	Landform	Code	Structural Landform
Endogenic	Structural	S17	Structural Valley
Exogenic	Denotational	D1	Eroded Hills

There are some aspects of the approach in geological mapping like shape of slope, the pattern of the ridge and patterns of drainage. the drainage pattern classified into a basic drainage pattern and a flow pattern of modification. The basic streaming pattern is a characteristic drainage pattern that can be distinguished from other drain patterns, while the modification flow pattern (Figure 4) [28][1]. Different drainage pattern and changed from the basic pattern, but the general pattern remains dependent on the underlying pattern, the characteristics of the basic drainage pattern and modification can be seen in Table 5[8][5].

**Figure 4.** Base Patterns of River Flowing and River Flow Modification Patterns**Table 5.** River Patterns and Their Characteristics

River Patterns	Characteristics
Dendritic	Flat sedimentary rock layers or crystalline rock association, that are non-uniform and resistant. Regionally, the flow area has a slope, the type of drainage pattern forms a branch spread like a shade tree.
Parallel	Generally, shows areas of moderate to steep slopes and can be found also in areas of elongated hills. There is often a transition pattern between dendritic patterns with parallel patterns. The elongated hills form with parallel drain patterns reflecting the hills are influenced by folding.
Trellis	Sedimentary sediments dipped, volcanic rocks or low-grade metasedimentary with clear weathering differences. The type of drainage pattern usually faces on the side along the subsequent stream.
Rectangular	Fault that have a slope angle, do not have a refractive layer of rock and often show an uninterrupted flow pattern.
Radial	Volcanic area, intrusion (dome) and the remnants of erosion. Radial drainage patterns in volcanic areas are referred to as multi radial drainage patterns. Note: the radial drainage pattern has two systems: the centrifugal system (spreading out from the center), means that the area is domed or conical, while the centripetal system (spreading toward the center) means that the area is a hollow.
Annular	Structure of dome / cone, basin and possibly <u>stocks</u>
Multi basinal	Deposition in the form of dunes result of landslide with difference of grinding or bedrock smoothing, is area of movement of soil, volcanism, solubility and melting of snow (permafrost)

Geological structure analysis is essential to estimate the force or deformation in rock outcrop. The geological structure analysis used the Stereonet Plot software. Stereographic projections are shown in Figure 5.

**Figure 5.** Stereographic projection of fields in a fold (a) Beta Diagram and (b) Phi diagram

### 3. Result and Discussion

#### 3.1 Geomorphology

In geomorphological analysis refers to morphometric, morphographic, and morphogenetic aspects. In these three aspects are reviewed the land shape, slope, lithology, and the flow pattern developed in the research area.

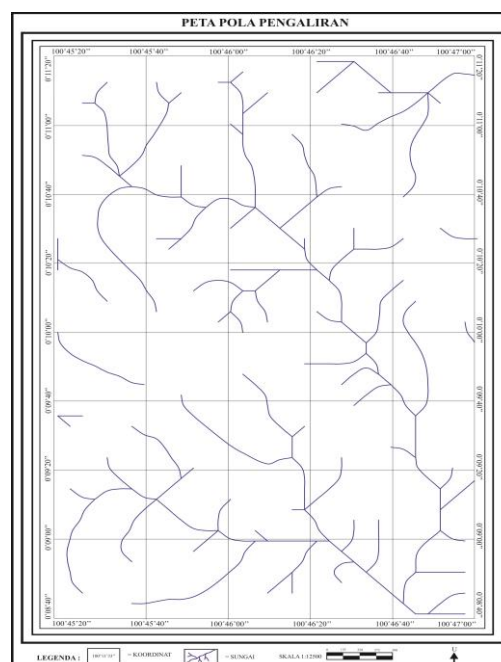
##### 3.1.1 Morphometry

Based on the results of morphometric analysis the landforms of the research area are classified into two relief classes, namely: Corrugated Hilly Slope reliefs and Sharp Steep Slope reliefs. Corrugated Hilly Slope relief has a slope percentage value from 15 until 40%, while Sharp Steep Slope relief has a slope percentage from 56 until 125%.

##### 3.1.2 Morphography

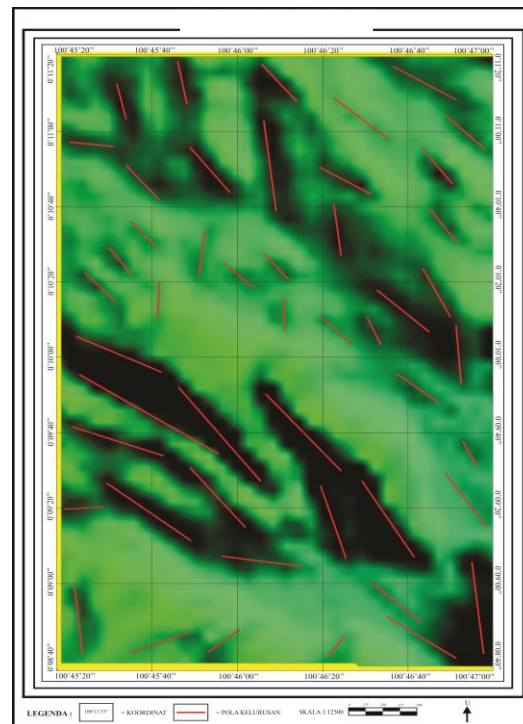
The research area is composed of land forms with elevation values ranging from 87 - 437 meter above sea level, with valleys U and V shaped, and type of drainage pattern is sub-dendritic. Landforms in the research area are classified into two, namely: Steep Hills and Slightly Steep Hills. The type of drainage pattern that dominates in the study area is sub-dendritic, shown in Figure 6. Upstream of the research area dominates in the Northwest part, particularly in areas with steep slopes with elevation values ranging from 200 - 350 m and flowing downstream of the southeast trending river slightly steep slopes with elevation values ranging from 150-200 m. Some of the main rivers distribution is in the center of the research area and flow towards the Southeast with elevation values ranging from 85 - 100 m, shown in (Figure 7). Analysis of negative alignment patterns (Figure 8) taken from satellite imagery by marking several weak zones in dark black shows the direction to Northwest-Southeast domination (Figure 4.3). This negative alignment direction is the controller for the flow pattern in the research area.

The lithology in this flow pattern are dominated by claystone and sandstone, with grain sizes ranging from fine to very fine. The sub-dendritic flow pattern of the research area has a steep slope. The structure and lithology's found in this research area are influenced the process of forming this flow pattern.

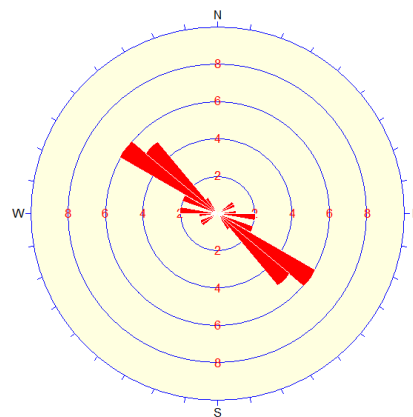


**Figure 6.** Flow pattern of the research area shows sub-dendritic types





**Figure 7.** The map is shown the pattern of negative alignment of the study area.



**Figure 8.** The alignment pattern from rose diagram projections relatively is shown Northwest to Southeast direction.

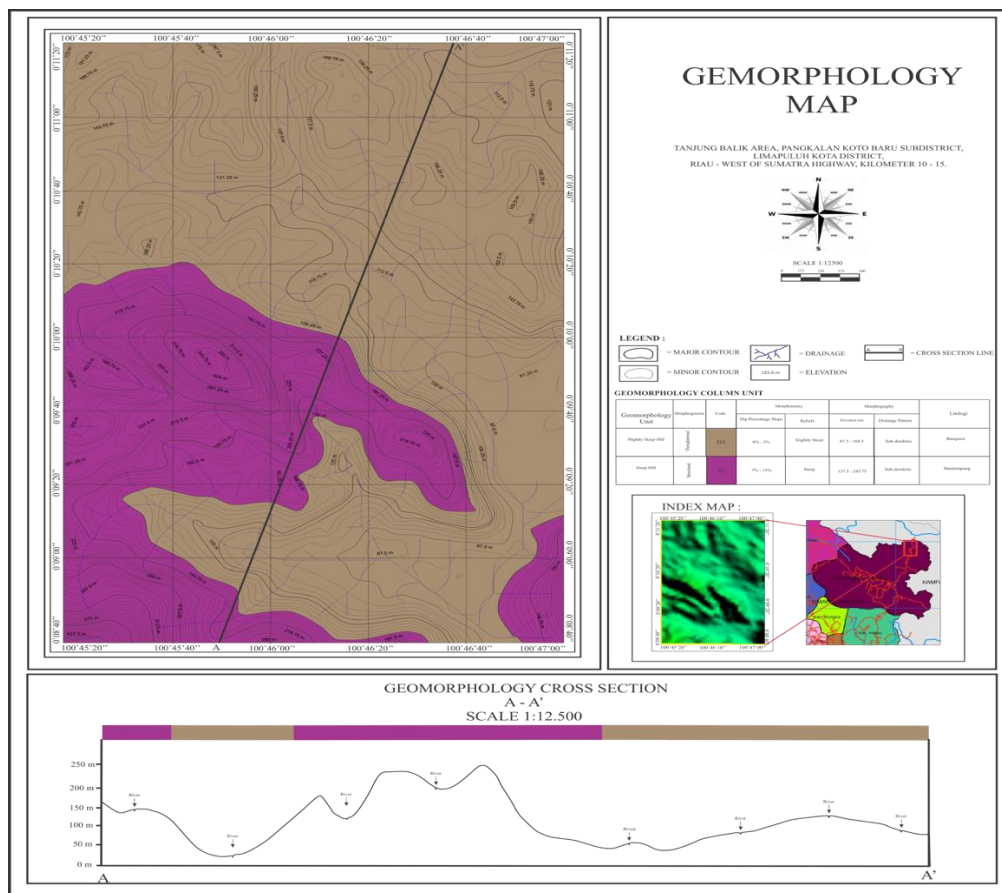
### 3.1.3 Morphogenetic

The results of geomorphological map analysis and field appearance, morphogenetics of the study area are classified into two, namely: Structural and Denudational origin.

### 3.2 The Geomorphology Units of Research Area

Geomorphological classification unit is based on the results of geomorphological analysis through morphometry, morphography and morphogenetic aspects. Result of the geomorphological analysis, the study area was classified into two geomorphological units, namely: Structural Steep Hills Geomorphological Unit and Denudational Steep Hills Geographical Unit. The Structural Steep Hill Geomorphology Unit (S2) is located in the Southern region of the research area with a distribution percentage around 27%, while the Denudational Steep Hill Geomorphology Unit (D3) is dominated in the North, West, East and slightly in the South with a distribution percentage of 73% , shown in the geomorphological map Figure 9.





**Figure 9.** Geomorphology map of research area.

### 3.2 Structural Steep Hill Geomorphology Unit(S2)

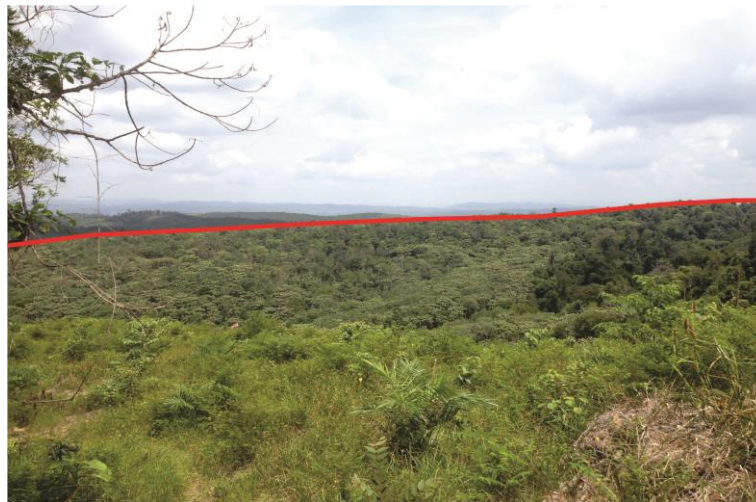
Structural Steep Hill Geomorphology Unit have characterizations topography with steep hill relief, the steep slope from 56 to 125%. Elevation differences are around 170 m, range of values elevation from 150 to 320 meters above sea level, which has a very strong erosion rate. This landform unit is characterized by a tight and elongated contour pattern and has a steep to very steep slope. Lithologies of this unit are clay and silt. Based on the shape of the relief and slope, this unit is called the Structural Steep Hill Geomorphology Unit, shown in Figure 10.



**Figure10.**Photogeology shows the Structural Steep Hills Geomorphology Unit

### 3.2.2 The Denudational Steep Hill Geomorphology Unit (D3)

The Denudational Steep Hill Geomorphology Unit has characterization of a slightly steep hill topography with slope of 15-40%. Elevation differences are around 70 m and elevation value range from 80 to 150m. This unit have experience weather and erosion. This landform unit is characterized by a rather tight and elongated contour pattern and has a steep slope. Lithologies of this unit are sandstone and silt. Based on the shape of the relief and the slope of the slope, this unit is called the Denudational Steep Slope Geomorphology Unit, shown in Figure 11.



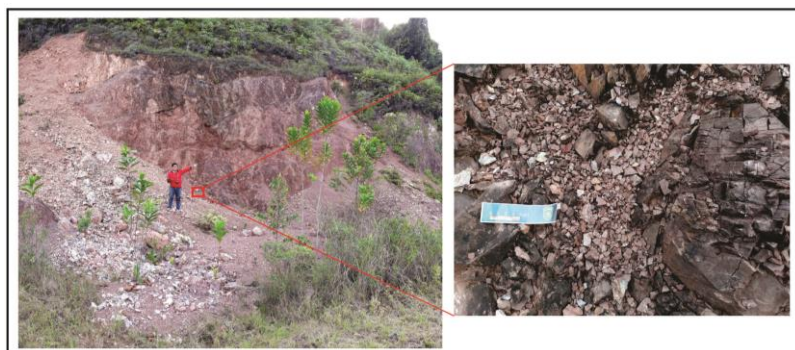
**Figure11.**Photogeology shows the Denudational Steep Hill Geomorphology Unit

### 3.3 Structural Geology Analysis

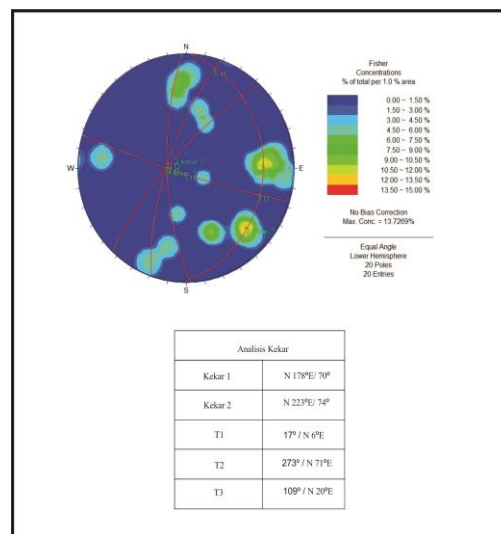
The geological structure is encountered in the study area at Station 7 and Station 8 in clay stone.

#### 3.3.1 Joint Structure Analysis at Station7

Joint is a geological structure caused by the presence of force, either in the form of pressure or tension which results in an object experiencing fracture. Based on the results of the field activities there are joint structure in clay stone at Station 7, which is shown in Figure 12. The reconstruction data is obtained a solid reading with the direction of the *conjugate joint*, 1N 178 ° E / 70 °, 2N 223 ° E / 74 °, which have value of  $\sigma_1$ : 17 °, N 6 ° E,  $\sigma_2$ : 273 °, N 71 ° E,  $\sigma_3$ : 109 °, N 20 ° E. The results of joint analysis with the main stress are obtained to the North-South, which are indication of landslide. Outcrop of joint structure analysis is shown in Figure 13.



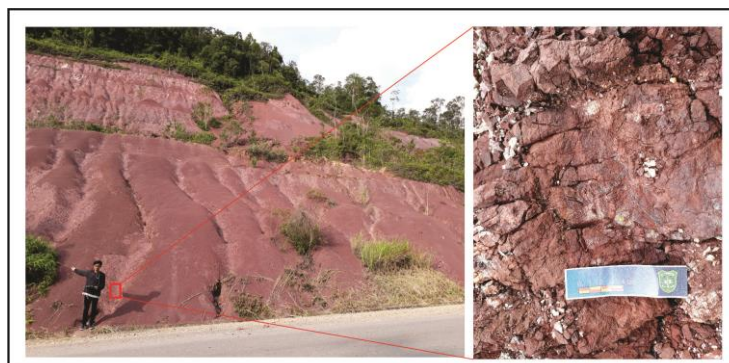
**Figure12.**Photogeology shows the outcrop joint data collection at Station 7



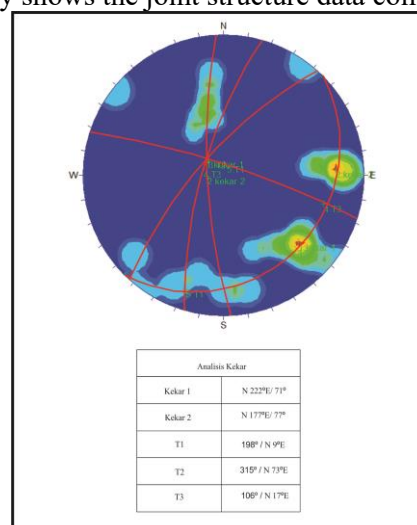
**Figure 13.** Stereonet joint structure analysis at Station 7

### 3.3.2 Joint Structure Analysis at Station 8

In the joint reconstruction of Clay stone at Station 8 (Figure 14) in the research area was obtained with joint readings with direction of the *conjugate joint* 1N 222 ° E / 71 °, 2N 177 ° E / 77 °, which has value of  $\sigma_1$ : 198 °, N 9 ° E,  $\sigma_2$ : 315 °, N 73 ° E,  $\sigma_3$ : 106 °, N 17 ° E. Result analysis is concluded main stress to the North-South as an indication of landslides. Joint structural analysis by stereonet is shown in Figure 15.



**Figure 14.** Photo geology shows the joint structure data collection location at Station 8



**Figure 15.** Stereonet analysis of the joint structures at Station 8

#### 4. Conclusion

Geomorphological conclusions of the research area are classified into two, namely Structural Steep Hills Geomorphology Unit (S2) and Denudational Steep Hill Geomorphology Unit (D3). The Structural Steep Hills Geomorphology Unit (S2) is in the Southern region of the research area with a distribution percentage around 27%, while the Denudational Steep Hill Geomorphology Unit (D3) dominates in the North, West, East and slightly in the South with a distribution percentage around 73%. Flow patterns are classified as sub-dendritic types. Geological structure analysis of the joint shows the main stresses that have North-South direction relatively.

#### 5. Acknowledgement

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