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RESEARCH ARTICLE

Petrography, Geology Structure and Landslide Characterization of Sumatra Fault Deformation: Study Case In Km 10-15 Highway, Koto Baru Sub District, West of Sumatra

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Abstract

Research area is around Tanjung Balik, Koto Baru Sub Base, Lima Puluh Kota District, West Sumatra Province. Located along the highway Km 10-15 Riau – West Sumatra and the coordinate around 00°08'40 '' LU - 0°11'20 '' N and 100°45'20 '' BT - 100°47'00 '' BT. The purpose of research to identify petrography, microstructure, types of landslides and the geological condition. The methods using polarization microscope, stereography, landslide identification survey and geological mapping. The result of study shows the petrography analysis of lithology of study area are classified into three types of rocks are Feldspathic Greywacke, Lithic Arenite, and Slate. Microstructures trending system show the foliation structure that is relatively Southeast-Northwest. Types of landslide which dominates in the research area are debris avalanche and translational landslide. Geological analysis show some of rock units are classified into two units: Sandstone Unit and Slate Unit. Sandstone Unit spread in the northern part of the study area, while Slate Unit spread in the southern part of the study area. The characteristics of these rocks showed Pematang Formation.

Keywords: Landslide, Petrography, Microstructure, Geology

1. Introduction

Location is administratively in the Lima Puluh Kota District of West Sumatra Province. The geographical position of the research area is located between 0°08 'LU - 0°11' N and 100°45 'BT - 100°47' BT. Elevation of research area are based on a topographical, the lowest elevation 80 meters above sea level until the highest elevation 345 meters above sea level. The purposes of research to figure out the geological condition, lithology characterization, microstructure patterns and types of landslides to happened in the area of research.

Definition of landslide is a movement down the slope of the land mass and or rocks making up the slope toward the foot of the slopes, as a result of disruption of the stability of soil or rocks making up the slope. If the land mass dominates the moving masses and it is moving through a field on a slope, in the form of an inclined plane or curved, then the movement is called a landslide (Nugraha et al., 2015; Taylor et al., 2015; Chang and Wan, 2015; Tacconi Stefanelli et al., 2016; Margottini et al., 2013; Sassa et al., 2014; Xu et al., 2015).

The factor of the movement on the slope also depends on the condition of rocks and soil making up the slope, geological structure, rainfall, vegetation cover and land use on the slopes, but the outline can be distinguished as natural and human factors (Shanmugam, 2015; Taylor et al., 2015; Kumar et al., 2015; Choanji et al., 2018).

Factor of topography and morphology of the zone located in Tanjung Balik Sub Base, Lima Puluh Kota District included into the path of Barisan Hill (Sumatra et al., 2018), which gives effect to the slope of the land is quite high, hydrology rainfall with high intensity and quality of physical-chemical soil, then some of these factors to led speed ground movement occurs (Mairizki and Cahyaningsih, 2016; Cahyaningsih, 2016; Yuskar et al., 2017; Catur Cahyaningsih, Arrachim Maulana Putera, Gayuh Pramukti, 2018). The geological structure in the form of faulting also resulted in the region's vulnerability to ground motion hazard (Samuel et al., 1995; Crampin and Gao, 2012; Fatriadi et al., 2017; Dewandra Bagus Eka Putra, yuniarti yuskar, catur cahyaningsih, 2017; Shah, 2015; Shah, 2013). The Sumatra Fault Zone classified as a highly active fault, which is triggered some geological hazard such as earthquake, tsunami, and landslide.

The area in the Regional Geological Map Sheet Pekanbaru, Sumatra, Issue 2, Scale 1: 250,000, shown in Fig 1. The unavailability of small scale maps making it difficult to get more detail information about the geology of the area and geological structures, especially in West Sumatra. This research is essential to aim at more comprehensively data about lithology, deformation; microstructure has been working in the research area, which causes frequent landslides.

The research area consists of Four Formation namely: Kuantan Formation (Puku), Bahorok Formation (Pub), Pematang Formation (Tlpe) and Sihapas Formation (Tms), the stratigraphic sequence of Central Sumatera Basin shown in Table 1.

a. Kuantan Formation (Puku)
The oldest rocks exposed in the study area is meta-sediments and slate spread to the Southwest of research area, which consists of slate, quartzite and meta-quartz arenite, this formation age Paleozoic Permian - Carbon. Mesozoic - Paleozoic rock , consisting of meta-volcanic and hornfel, slate and a bit of old limestone with age Permian - Carbon to Jurassic. These formations are spread in the Southwestern of research area (A. J. Barber, M. J. Crow, 2005).

b. Formation Bahorok (Pub)
Bahorok formation composed of metamorphic wacke, slate, metamorphic quartz sandstone, siltstone, metamorphic conglomerate, which suspected Carbon to Early Permian age (A. J. Barber, M. J. Crow, 2005).

c. Pematang Formation (Tlpe)
Pematang Formation (Tlpe) is a bed of sedimentary Central Sumatra Basin, the age is middle Eocene to Oligocene, which is precipitated as unconformity bedrock on the top. This formation consists of red and mottled mudstone, conglomerate, breccia and sandstones conglomerate deposited in fluvial - lacustrine environment (A. J. Barber, M. J. Crow, 2005).

d. Formation Sihapas (Tms)
Sihapas Formation (Tms) is the Early Miocene consists of quartz sandstone, shale carbonaceous siltstone, and conglomerates (A. J. Barber, M. J. Crow, 2005).

Research area is part of the Central Sumatra Basin, one of the three basins *Sumatra back-arc* basin formed during the period of Early Tertiary (Eocene - Oligocene), consists of a series of blocks of horst and graben formed in response to the extension behind the arc (A. J. Barber, M. J. Crow, 2005). The thickness of the sediments in the basin reached 2.5 - 3 km, consists of sequences *sync - rift* and *post-rift* Pemantang group in Eocene - Oligocene, Early Miocene age is Sihapas Group, Petani Group is Middle Miocene - Pliocene and Plio-Pleistocene of Minas Formation. This basin with the North Sumatra Basin is separated by Asahan Arc, while the South Sumatra basin separated by Tiga Puluh High (Widayat et al., 2016; Natalie et al., 2015; De Coster, 1974; Cahyaningsih et al., 2018).

Structures of the research area characterized by a pattern of blocks transcurrent fracture and fault shows in Fig 2. Fault blocks System have a parallel orientation with the North-South form a series of horst and graben (A. J. Barber, M. J. Crow, 2005). The pattern of existing structures in Central Sumatra Basin is the result of at least three separate major tectonic phases, namely orogenesis of Middle Mesozoic, tectonics of Late Cretaceous-Early Tertiary, and orogenesis of Plio–Pleistocene (De Coster, 1974; A. J. Barber, M. J. Crow, 2005).

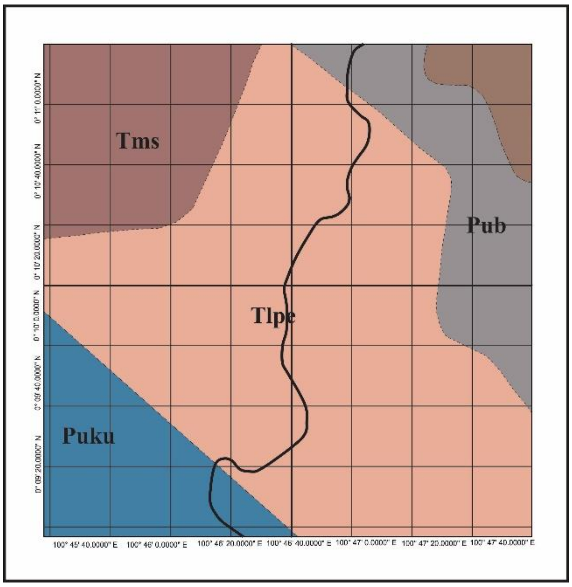
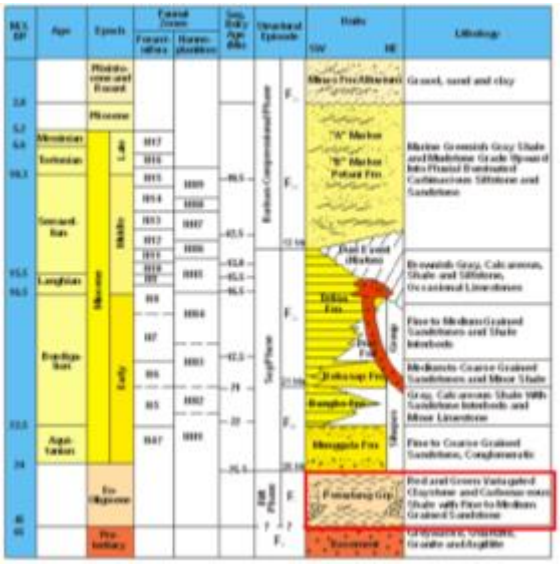


Fig 1. Map show geology regional of research area.

Central Sumatra Basin has two sets of faults which has trending pattern North-South and Northwest-Southeast. North–South fault trend estimated age in Paleocene, while Northwest-Southeast fault trend estimated in Late Neocene age. Both sets of the fault repeatedly reactivated throughout the Tertiary by the forces at work (Holis and Sapiie, 2012; De Coster, 1974; Hidayat et al., 2016; Natalie et al., 2015; Joseph E. Laing, 1994).

Table 1. Stratigraphic sequence column of Central Sumatera Basin, red box show formation of research area.



There are seven types of landslides, namely: translational landslides, rotational landslide, block movement, soil creep, topple, debris flows and complex type (Hungr et al., 2014). From six types of landslides, translational and rotational landslide types most common in Indonesia, it is because a high degree of rock weathering, so that the soil is formed thick enough (Umitsu et al., 2007; Santoso et al., 2013; Yaman et al., 2013; Cahyaningsih et al., 2018; Catur Cahyaningsih, Arrachim Maulana Putera, Gayuh Pramukti, 2018).

Figure 2. Framework for regional tectonic Central Sumatra Basin, red box show research location

2. Method

The object of research are the slopes that failed along Riau-West Sumatra Highway Km 10-15. Type of lithology, coordinates of landslides location, geology structure, type and geometry landslides become the focus of the research object. Lithological sampling is orientation sample.

The methods are consists of the polarization microscope, stereo net and landslide identification survey and geological mapping. Data processing phase consists of laboratory and analytical work in the studio. The analysis in the laboratory is petrographic analysis. While the analysis is done in the studio include geological mapping, analysis of microstructures (MONICA PRICE & WALSH, 2005; GEORGE, 1943).

Geological mapping method is plotting by GPS (the Global Positioning System) and a description of the type of lithology, texture, grain size, roundness, sorting, fabric, structure(Aydin, 2010), and mineral composition. The petrographic analysis aims to determine the volumetric amount of the composition to determine precisely the name, and rock texture, this method using the polarizing microscope (Mennell, 1913; Hughes, 1982). Under a microscope, the percentage of grain composition is done by point counting method. Thin section of clastic sedimentary rocks are encountered in the study area were classified using the classification of clastic sedimentary rock (Fig 3) which makes the percentage of some components such as grains of quartz, feldspar, rock fragments, matrix (fine material) and cement solution; GEORGE, 1943; Correns et al., 1969; Mairizki and Cahyaningsih, 2016; Cahyaningsih et al., 2018). Metamorphic rocks are classified based on both composition and texture (grain size, mineral composition, presence or absence of foliation) (Frost and Frost, n.d.), shown in Table 2.

The stereo net method use rose diagram, the data are based on thin section of rock samples, which taken by oriented. Reading microstructure as foliation analyzed to get directions trend (ÇelIk, 2013; Aydin, 2010; Sharma et al., 2015; Nlomngan et al., 2013). Methods to determine the type of landslide using Varnes classification 1977; Hungr et al., 2014), which divides into seven types of landslides are: translational slides, avalanches rotation, block movement, rock fall, soil creep, and complex landslide, are shown in Table 3.

Weathered rock profile description do when analyzing types of landslides. Weathering is the process of changing rocks into the soil, physical or mechanical and chemical processes *(decomposition) (Yaman et al., 2013; Onyelowe and Okoafor, 2012; Vinay and Mahalingam, 2015; Cahyaningsih, 2016; Cahyaningsih et al., 2018;* Yaman et al., 2013; Onyelowe and Okoafor, 2012*;* Vinay and Mahalingam, 2015) (Cahyaningsih, 2016; Cahyaningsih et al., 2018). Decomposition process can lead to new minerals (Anderson et al., 2002)

3. Result

Lithology constituent in the research area was classified into 3: feldspathic greywacke, lithic arenite, and slate. Feldspathic Greywacke located at Station 2 area of research has the characteristics of fresh color is white gray, weathered color is brownish gray, grain size 1 mm, rather compact, rounded, fine texture, close fabric, well sorted and high porosity, shown in Fig 4.

The thin section shows the optical characteristics color of Plane Polarized Light (PPL) is dirty white, on Cross-Polarized Light (XPL) color is grayish black, grain shape is rounded, well sorted, closed fabric, mineral composition consists of quartz, feldspar, rock fragments and cement, with amount 45%, 35%, 5% and 15% respectively, while other minerals include of accessory mineral less than 1%, this rock classified as feldspathic greywacke, shown in Fig 5.

Fig 4. Geological photo shows Station 2 a) feldspathic greywacke outcrop b) feldspathic greywacke outcrop from near angle c) hand specimen of feldspathic greywacke.

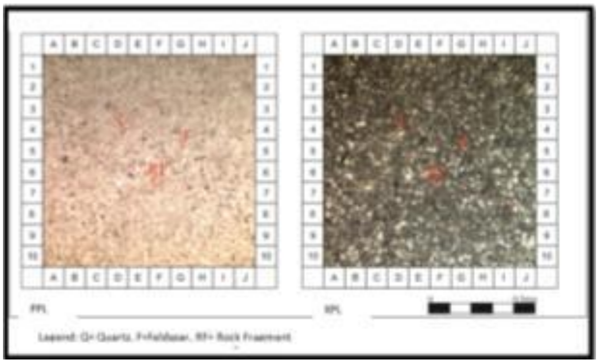


Fig 5. Photomicrograph shows the results of petrographic thin section of feldspathic greywacke at Station 2.

Lithic arenite at Station 3 of research area shows the characteristics of fresh-colored grayish white, the weathered-colored is grayish-brown, grain size is medium, compaction is rather compact, rounded, medium texture, the fabric is closed, medium sorted and high porosity, shown in Fig 6.

Fig 6. Geological photo shows Station 3 **a)** lithic arenite outcrop b) lithic arenite outcrop from near angle c) hand specimen of lithic arenite.

The thin section shows the optical characteristics color of Plane Polarized Light (PPL) is dirty white, on Cross-Polarized Light (XPL) color is brownish black, the mineral composition consists of quartz, feldspar, rock fragments, cements, with amount 40%, 25%, 25%, and 10% respectively. As the main mineral is quartz and feldspar. This rock classified into lithic arenite, shown in Fig 7.

Slate located at Station 7 areas of research shows the characteristics the fresh color is reddish brown, the weathered color is dark brown, the grain size is very fine, derived from metamorphic mudstone, the texture is relict tar, the structure is foliation and there are geological structures such as joint. Slate outcrop can be seen in Fig 8.

The thin section of slate shows the optical color characteristics of Plane Polarized Light (PPL) is dark brown, on Cross-Polarized Light (XPL) color is brown, composition of mineral consist of clay, silt and sand, with amount 70%, 15% and 5% respectively. The grain size is 0.2mm. Photomicrographs showed a low degree metamorphism indication is foliation called *slaty*. The name of rock called *slate*, shown in Fig 9.

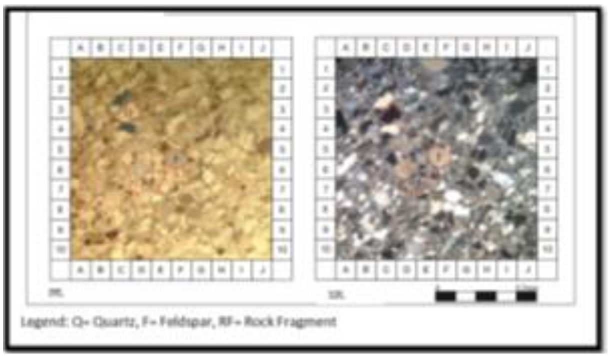


Fig 7. Photomicrograph shows the results of petrographic thin section of lithic arenite at Station 3.

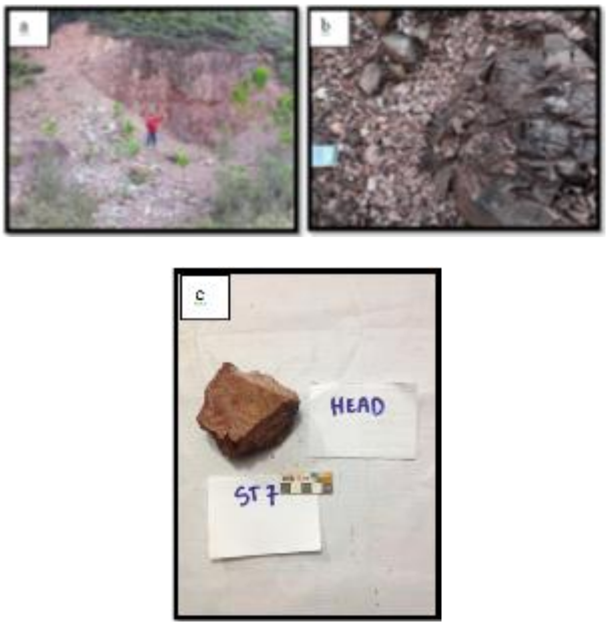


Fig 8. Geological photo shows Station 7 a) slate outcrop b) slate outcrop from near angle c) hand specimen of slate.

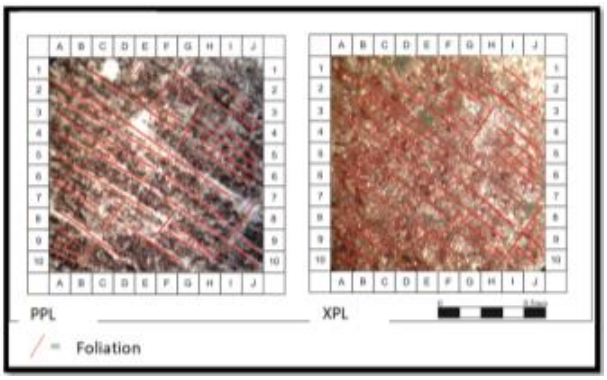


Fig 9. Photomicrograph shows the results of petrographic of slate at Station 7.

Analysis of slate microstructure with 40 times magnification using a polarization microscope showed the presence of foliation structure with a distance of 0.1 mm, the orientation of azimuth direction with average 300° and *back azimuth* direction average is 120°, showed in Fig 10a. Relative trend pattern is Northwest-Southeast, which have same direction with Sumatra Fault Zone, shown in rose diagram in Fig 10b. The analysis of the negative lineation pattern of the study area which is relatively trend North-West-Southeast, this further strengthens the evidence that microstructures are formed by this lineation pattern that has a large influence from the Sumatra Fault. The analysis is shown as lineation map and Rose Diagram in Fig 14.

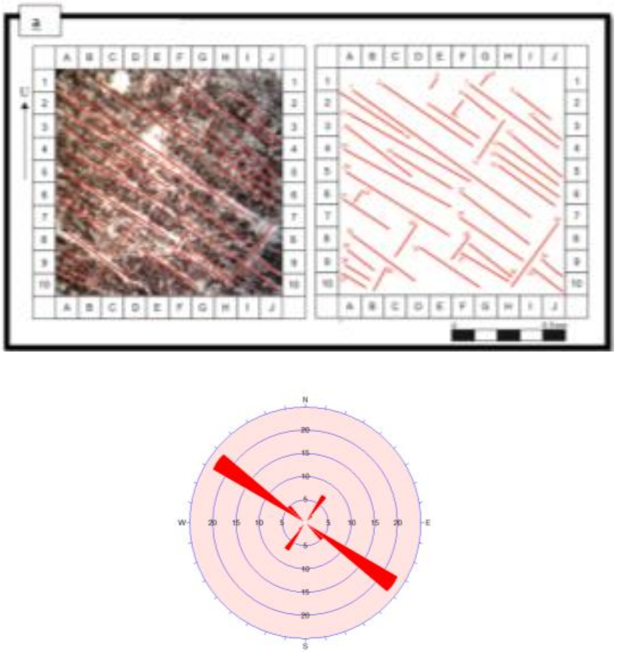


Fig 10. (above) Photomicrograph show microstructure analysis of slate at station 7, red line is foliation; (below) Rose diagram analysis show trend pattern from Northwest-Southeast.

Slate at 8 Stations in the research area showed the presence of the orientation directions of foliation with *azimuth* average 290°, *back azimuth* average 110°, showed in Fig 11 Rose diagram analysis show pattern of relative trend is Northwest-Southeast, can be seen in Microstructure analysis of foliation trend patterns at Stations 8 and 7 relatively the same direction. Microstructure presence caused by the fault, estimated in Late Neocene age.

Based on analysis of the type of landslides in research area are classified into two, namely, debris avalanche and translational landslide. Material debris avalanche with a mixture of clay and silt moving at relatively high speed, with a steep slope topography. The very high degree of weathering profile reached number 6 in the dominant pattern of relative landslide Northwest-Southeast. Spreads almost 80% throughout the research area, debris avalanche type can be seen in Fig 12.

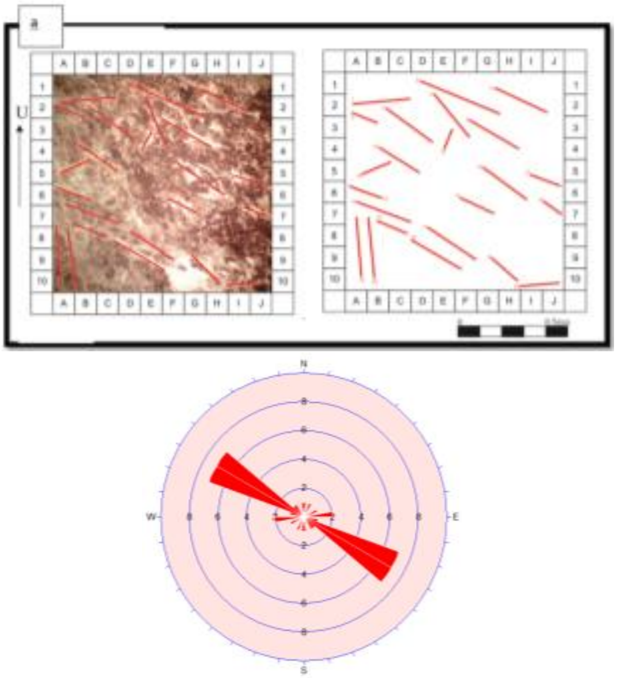


Fig 11. (above) Photomicrograph show foliation microstructure analysis of slate at Station 8, red line is foliation structure. (below) Rose diagram analysis show Northwest-Southeast trending pattern.

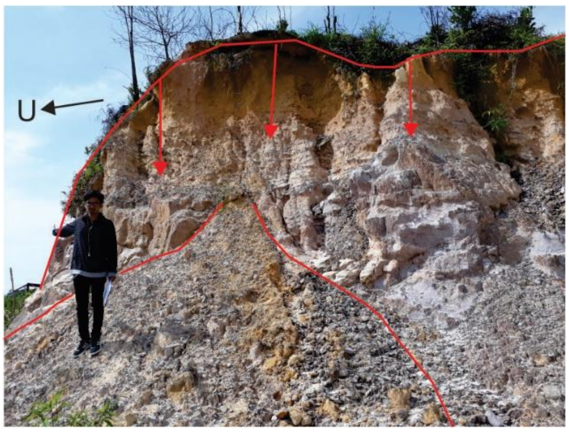


Fig 12. Photo geology show debris avalanche type in research area

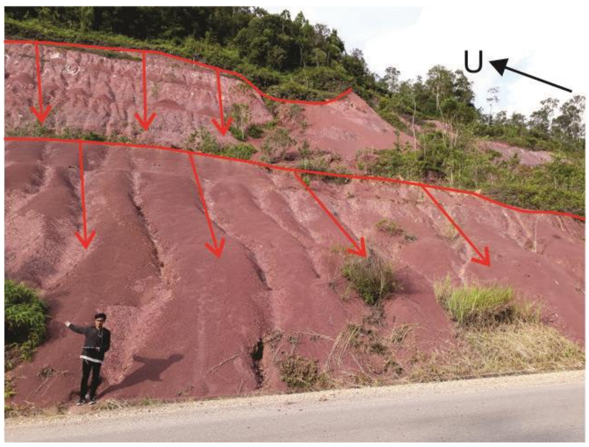


Fig 13. Photo geology show translational landslide in research area.

Translational landslide with the material such as silt and clay moving on slopes gently to undulating, with a degree of weathering profile is very high with profile number is 6. Pattern of landslides relatively show trend system between Northwest-Southeast. Spreads almost 20% in the research area, the translational landslide can be seen in Fig 13.

Based on the geological analysis of research area consist of two types of rocks unit, namely Slate Unit and Sandstone Unit. Sandstone unit classified into two: feldspathic greywacke and lithic arenite. This unit spread in the Northern part of the research area, while Slate Unit spread in the Southern part of the research area. Those Lithologies are interpreted in the study area included in Pematang Formation, which is part of the Formation in Central Sumatra Basin. Geological map of the study area can be seen in Fig 15 and stratigraphic column of research area consist of Slate Unit as the oldest and followed by Sandstone Unit as the youngest rock unit, show in Table 5.

4. Conclusion

Based on the analysis, Pangkalan Koto Baru, Riau-Sumbar Highway Kilometer 10-15, it can be concluded that: Geologic research area is divided into two types, namely Slate Units and Sandstone Units. Compose the lithology in research area are feldspathic greywacke, lithic arenite, and slate. Microstructure experienced is foliation structure, which has trend is Southeast-Northwest, which has influenced by Sumatra Fault. This type of movement are dominated by debris avalanches and translational landslide type. This landslide mapping needs further research, especially on the Riau-West Sumatra Highway

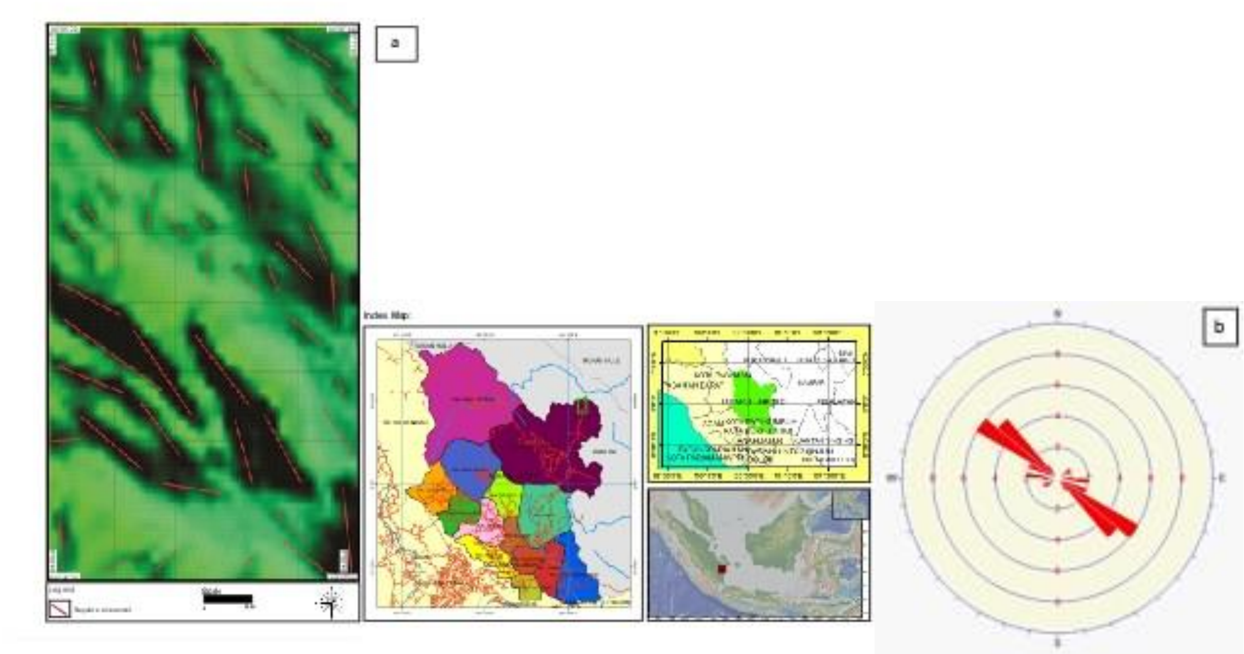
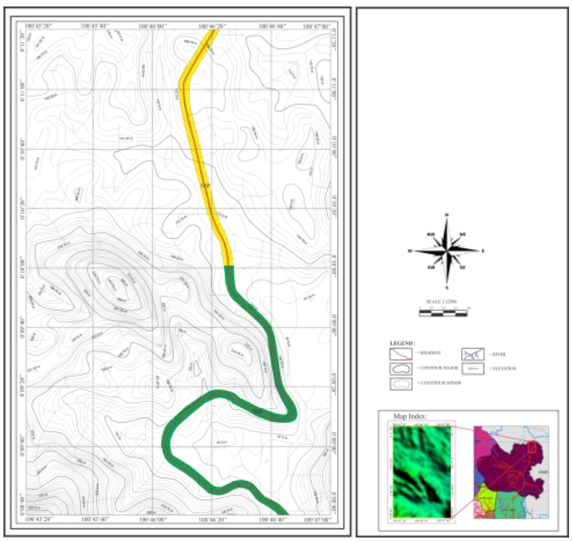


Fig. 14. Map is showing negative lineament pattern and he lineament trend pattern is Northwest – Southeast.



CODE COLOR	ROCK UNIT	DESCRIPTION
SBP	Sandstone Unit	Lithology Constituent are feldsphatic greywacke and lithic arenite. Feldspathic Greywacke has the characteristics of fresh color is white gray, weathered color is brownish gray, grain size 1 mm, rather compact, rounded , fine texture, close fabric, well sorted and high porosity. Optical characteristics color of Plane Polarized Light (PPL) is dirty white, on Cross Polarized Light (XPL) color is grayish black, grain shape is rounded, well sorted, closed fabric, mineral composition consists of quartz around 45%, feldspar around 35%, rock fragments around 5% and cement 15%. Lithic arenite shows the characteristics of fresh-colored grayish white, the weathered-colored is grayish-brown, grain size medium, rather compact, rounded, medium texture, fabric is closed, medium sorted and high porosity. Optical characteristics color of Plane Polarized Light (PPL) is dirty white, on Cross Polarized Light (XPL) color is brownish black, mineral composition consists of quartz around 40%, feldspar around 25%, rock fragments around 25% and cement around 10%.
SBS	Slate Unit	Slate shows the characteristics of fresh color is reddish brown, the weathered color is dark brown, grain size is very fine, derived from metamorphic mudstone, texture is relict tar, structure is foliation and there are geological structures such as joint. Optical color characteristics of Plane Polarized Light (PPL) is dark brown, on Cross Polarized Light (XPL) color is brown, composition of mineral consist of clay 70%, silt 15%, and sand 5% with a size of 0.2 mm. Photo micrographs showed a low degree metamorphism indication that is foliation called *slaty*.

Fig 15. Geological Map of research area.

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References

A. J. Barber, M. J. Crow, J.S.M., 2005. Sumatra Geology, Resources and Tectonic. The Geological Society London.

Anderson, S.P., Dietrich, W.E., Brimhall, G.H., 2002. Weathering profiles, mass-balance analysis, and rates of solute loss: Linkages between weathering and erosion in a small, steep catchment. Bull. Geol. Soc. Am. 114, 1143–1158. doi:10.1130/0016-7606(2002)114<1143:WPMBAA>2.0.CO

Aydin, A.L.İ., 2010. Application of the Normalized Full Gradient (NFG) Method to Resistivity Data 19, 513–526. doi:10.3906/yer-0903-2

Cahyaningsih, C., 2016. Hydrology Analysis and Rainwater Harversting Effectiveness as an Alternative to Face Water Crisis in Bantan Tua Village Bengkalis District-Riau. J. Dyn. 1, 27–30. doi:10.21063/JoD.2016.V1.1.27-30

Cahyaningsih, C., Ritonga, A.L., Aldila, S., Zulhikmah, Z., 2018. Lithofacies And Depositional Analysis Environment Of West Section Kolok Nan Tuo Village, Sawahlunto City, West Of Sumatera. J. Geosci. Eng. Environ. Technol. 3, 128. doi:10.24273/jgeet.2018.3.2.340

Catur Cahyaningsih, Arrachim Maulana Putera, Gayuh Pramukti, M.M.S., 2018. Geology and Geochemistry Analysis for Ki Index Calculation of Dompak Island Granite Bauxites to Determine the Economical Mineral. Springer Singapore. doi:10.1007/978-981-10-8471-3

Catur Cahyaningsih, Puja Fransismik Crensonni, D.B., 2018. Unicharacteristic of Geomorphological Landscape & Depositional Environment in Talawi Hilir : Geotourism Value of Sawahlunto 3, 42–51.

Çellk, H., 2013. The effects of linear coarse-grained slope channel bodies on the orientations of fold developments: A case study from the Middle Eocene-Lower Oligocene Ki{dotless}rkgeçit Formation, Elazi{dotless}ğ, eastern Turkey. Turkish J. Earth Sci. 22, 320–338. doi:10.3906/yer-1202-5

Chang, S., Wan, S., 2015. Geoscience Frontiers Discrete rough set analysis of two different soil-behavior-induced landslides in National Shei-Pa Park , Taiwan. Geosci. Front. 6, 807–816. doi:10.1016/j.gsf.2013.12.010

Choanji, T., Yuskar, Y., Putra, D.B.E., Cahyaningsih, C., Sakti, W., 2018. Clustering Slope Stability from Using Drone DEM Lineament Extraction And Rock Mass Rating In Pangkalan Koto Baru , West Sumatra , Indonesia J. Applied Geom. Inf. 2, 124–129.

Correns, C.W., Zemann, J., Koritnig, S., 1969. Introduction to Mineralogy, Crystallography and Petrology. doi:10.1007/978-3-662-28578-7

Crampin, S., Gao, Y., 2012. Plate-wide deformation before the Sumatra–Andaman Earthquake. J. Asian Earth Sci. 46, 61–69. doi:10.1016/j.jseaes.2011.10.015

De Coster, G.L., 1974. The Geology of the Central and South Sumatra Basins. Proc. Indones. Pet. Assoc. Third Annu. Conv. June 1974 77–110.

Dewandra Bagus Eka Putra, yuniarti yuskar, catur cahyaningsih, S.K., 2017. Title Rock Mass Classification System Using Rock Mass Rating (Rmr) Of A Cut Slope In Riau – West Sumatra Road. pp. 8–10.

Fatriadi, R., Asteriani, F., Cahyaningsih, C., 2017. Effectiveness of the National Program for Community Empowerment (PNPM) for Infrastructure Development Accelerated and Geoplanology in District of Marpoyan Damai, Pekanbaru. J. Geosci. Eng. Environ. Technol. 2, 53. doi:10.24273/jgeet.2017.2.1.30

Frost, B.R., Frost, C.D., n.d. IGNEOUS AND METAMORPHIC Essentials of Igneous and.

GEORGE, R.D., 1943. Minerals and Rocks, Soil Science. doi:10.1097/00010694-194311000-00011

Holis, Z., Sapiie, B., 2012. Fractured Basement Reservoirs Characterization in Central Sumatera Basin , Kotopanjang Area , Riau , Western Indonesia : an Outcrop Analog Study. Am. Assoc. Pet. Geol. Int. Conf. Exhib. Singapore 50735, 1–4.

Hughes, C.J., 1982. Igneous Petrology. Developments in Petrology 7.

Hungr, O., Leroueil, S., Picarelli, L., 2014. The Varnes classification of landslide types, an update. Landslides 11, 167–194. doi:10.1007/s10346-013-0436-y

Joseph E. Laing, B.P.A. and A.R., 1994. Structural evolution of the Pematang reservoirs, Kelabu-dingga Gas Fields, Sumatra. AAPG Int. Conf. Exhib.

Kumar, T., Negassa, L., Kala, P.M., 2015. RESEARCH PAPER GIS based Grid overlay method versus modeling approach – A comparative study for landslide hazard zonation (LHZ) in Meta Robi District of West Showa Zone in Ethiopia 235–250.

Mairizki, F., Cahyaningsih, C., 2016. Groundwater Quality Analysis in the Coastal of Bengkalis City. J. Dyn. 1.

Margottini, C., Canuti, P., Sassa, K., 2013. Landslide Science and Practice. Springer-Verlag Berlin Heidelberg.

Mennell, F.P., 1913. A Manual of Petrology.

Natalie, O., Bettis, E.A., Zaim, Y., Rizal, Y., Aswan, A., Gunnell, G.F., Zonneveld, J., Ciochon, R.L., 2015. Paleoenvironmental conditions in the late Paleogene, Sumatra, Indonesia Natalie. J. ASIAN EARTH Sci. doi:10.1016/j.jseaes.2015.06.025

Nlomngan, J.P.S., Ndzana, S.P.M., Pountougnigni, P.N., Fils, S.N., Penaye, J., 2013. THE INFLUENCE OF BREAKING TECTONICS ON THE STRUCTURAL GUIDANCE OF STREAM FLOWS IN THE NORTHERN-EQUATORIAL PAN-AFRICAN CHAIN : THE CASE OF THE MAKENENE REGION 2, 1–8.

Nugraha, H., Wacano, D., Arya, G., Cahyadi, A., 2015. Geomorphometric characteristics of landslides in the Tinalah Watershed , Menoreh Mountains , Yogyakarta , Indonesia. Procedia Environ. Sci. 28, 578–586. doi:10.1016/j.proenv.2015.07.068

Onyelowe, K.C., Okoafor, F.O., 2012. Geochemistry of Soil Stabilization. ARPN J. Earth Sci. ©2006-2012 Asian Res. Publ. Netw. (ARPN). ISSN 2305-493X 1, 32–35.

Samuel, M.A., Hartono, L., Banner, F.T., 1995. A new stratigraphy for the islands of the Sumatran Forearc , Indonesia.

Santoso, D., Suroso, A., Kombaitan, B., Setiawan, B., 2013. Exploring the use of risk assessment approach for climate change adaptation in Indonesia : Case study of flood risk and adaptation assessment in the South Sumatra province. Procedia Environ. Sci. 17, 372–381. doi:10.1016/j.proenv.2013.02.050

Sassa, K., Canuti, P., Yin, Y., Programme, T.I., 2014. Landslide Science for a Safer Geoenvironment. Springer International Publishing Switzerland.

Shah, A.A., 2015. Kashmir Basin Fault and its tectonic significance in NW Himalaya, Jammu and Kashmir, India. Int. J. Earth Sci. 104, 1901–1906. doi:10.1007/s00531-015-1183-1

Shah, A.A., 2013. Earthquake geology of Kashmir Basin and its implications for future large earthquakes. Int. J. Earth Sci. 102, 1957–1966. doi:10.1007/s00531-013-0874-8

Shanmugam, G., 2015. The landslide problem 4, 109–166. doi:10.3724/SP.J.1261.2015.00071

Sharma, S., Sengupta, S., Roy, I., 2015. Identification of Failure Surfaces in Dragline Dumps of Opencast Coal Mines 4, 43–53.

Stefanelli, C.T., Segoni, S., Casagli, N., Catani, F., 2016. Geomorphic indexing of landslide dams evolution. Eng. Geol. 208, 1–10. doi:10.1016/j.enggeo.2016.04.024

Taylor, F.E., Malamud, B.D., Freeborough, K., Demeritt, D., 2015. Geomorphology Enriching Great Britain ' s National Landslide Database by searching newspaper archives 249, 52–68.

Umitsu, M., Tanavud, C., Patanakanog, B., 2007. Effects of landforms on tsunami f low in the plains of Banda Aceh , Indonesia , and Nam Khem , Thailand 242, 141–153. doi:10.1016/j.margeo.2006.10.030

Vinay, M., Mahalingam, B., 2015. Quantification of Soil Erosion By Water Using Gis and Remote Sensing Techniques : a Study of Pandavapura Taluk , Mandya District , Karnataka , India. ARPN J. Earth Sci. 4, 103–110.

Walsh, M.P.K., 2005. Pocket Nature Rocks and Minerals. Dorling Kindersley.

Widayat, A.H., van de Schootbrugge, B., Oschmann, W., Anggayana, K., Püttmann, W., 2016. Climatic control on primary productivity changes during development of the Late Eocene Kiliran Jao lake, Central Sumatra Basin, Indonesia. Int. J. Coal Geol. 165, 133–141. doi:10.1016/j.coal.2016.08.008

Xu, C., Xu, X., Shyu, J.B.H., 2015. Geomorphology Database and spatial distribution of landslides triggered by the Lushan , China Mw 6 . 6 earthquake of 20 April 2013 248, 77–92.

Yaman, B., KÖse, N., Akkemik, Ü., 2013. Changes in stem growth rates and root wood anatomy of oriental beech after a landslide event in Hanyeri, Bartin, Turkey. Turkish J. Agric. For. 37, 105–109. doi:10.3906/tar-1110-28

Yuskar, Y., Putra, D.B.E., Suryadi, A., Choanji, T., Cahyaningsih, C., 2017. Structural Geology Analysis In A Disaster-Prone Of Slope Failure, Merangin Village, Kuok District, Kampar Regency, Riau Province. J. Geosci. Eng. Environ. Technol. 2, 249–254. doi:10.24273/jgeet.2017.2.4.691.