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Remote Sensing Data Integration of Landsat 8 and SRTM for Geomorphological Characteristics Identification in Karst Pringkuku, Pacitan, East Java

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***Abstract*— Pringkuku is one of the transition areas where the morphology of karst began to develop toward the western part of Gunung Sewu Karst region. The purpose of this research is to identify the landform unit in Pringkuku's Karst as the result of geomorphological processes recorded by Landsat 8 image and SRTM image. The research was conducted by analyzing and dividing the landform units based on landform parameters such as flow patterns, slope forms, valley forms, and ridge patterns. Structural geology data such as a strike of joints and direct rock sampling are also used as the supporting data. The developing flow patterns are the multi-basinal and rectangular patterns in the western and eastern parts of the area respectively. Inferred from the analysis of joints pattern and stream lineament, the rectangular pattern is in direction NW - SE and NE – SW. The results of this research are two units of karst and structural landform, which are structural limestone hill unit in the eastern part of the area with 68.18% of spreading area of the total extent and conical limestone hill unit in western part of the area with spreading area of 31,82%.**

***Keywords*— landsat 8 image; SRTM image; landform; karst; Pacitan; remote sensing.**

I. INTRODUCTION

Karst geomorphology is a landform that has characteristics that develop in soluble rocks such as carbonates and evaporates results. Usually affected by underground river systems and surface river systems that disturbed, sinkholes and caves. This landscape is also characterized by open fractures and side-wall cavities [1].

Karst landform formed by the dissolution process on soluble rocks, such as limestone and affected by rain and CO2 [5]. Pringkuku is one of the transition areas where the morphology of karst began to develop toward the western part of Gunung Sewu Karst region. Karstification affected by two factors, they are controlling and triggering. Controlling factor related to the lithological conditions, rainfall conditions and elevation of landform conditions. Soluble mineral composition and cracks or joints will increase rock permeability and porosity, so water can be easily absorbed and dissolved the rock. High rainfall brings out abundant water supply as dissolution media. The elevation of the exposed rock position allows water to circulate vertically. The triggering factor is related to temperature and vegetation cover. The temperature will increase the activity of the organism that produces CO2 and determines the evaporation level. Vegetation cover affected CO2 levels as well [6].

The research area is more specifically part of the Gunung Sewu subzone which is a hill with karst landscapes stretching northwest-southeast. The southern part of Gunung Sewu is a coastal area that is directly adjacent to the Indian Ocean by erosion trenches. The northern part of Mount Sewu has a range that varies with the physiography around it. Gunung Sewu is limited by a semicircular line with a general direction northwest-southeast with the Baturetno Basin. The orientation of the hills and valley valleys on Mount Sewu varies geographically. The southern part is dominated by straightness trending northwest-southeast which is relatively parallel to the current coastline [7].

The research area is part of the Regional Geological Maps of Pacitan Sheets [11] and Surakarta-Girintoro Sheets [13] and is part of the Wonosari Formation and Oyo Formation. Some formations that make up the study area are sorted from young units to older units, including:

A. *Wonosari Formation*

This rock unit is composed of reef limestones, layered limestones, sliced limestones, sandstone limestone, and marl. Aged Middle to Late Miocene, and formed in shallow marine environments. This unit is deposited in a sea of abundance above the Nampol Formation, the lower part is sunning with the upper part of the Oyo Formation [11] It is estimated to have a thickness of more than 800 m [13].

B. Oyo Formation

This rock unit consists of limestone sandstone, tophaceous sandstones, limestone siltstone, tophaceous limestone, sandy marl, and tophaceous marl. Aged late in the Middle Miocene and formed in the depositional environment is the edge to the middle neritic. This unit overlaps the Nampol Formation in a sea-like manner, while the upper part is enclosed with the Wonosari Formation. Unit thickness is more than 200 m [11].

The Southern Mountain Region has experienced four tectonic liftings. The structural pattern in the study area with the northwest-southeast direction is generally a vertical shear fault, and northeast-southwest direction is generally a sinistrality shear fault that occurred due to the subduction of the Indo-Australian plate during the Eocene to Middle Miocene [4].

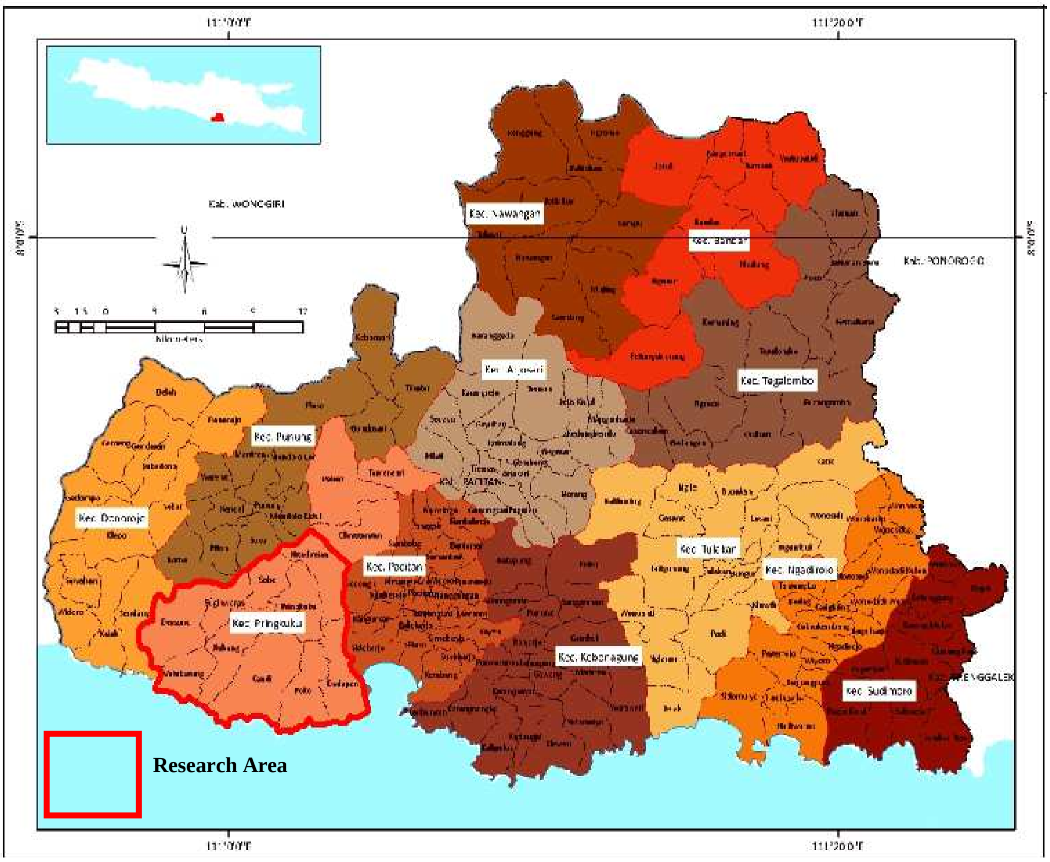

Fig. 1 The research location is in part of Pringkuku District, Pacitan Regency, which is at coordinates 110 ° 56'57.28 "E - 111°4'36.63" E and 8°9'6.35 "S - 8°15'25.35" S with an area of about 102 km.

Landform assessment can be determined from information on landscape distribution, surface composition and elevation from remote sensing data analysis [12]. Remote sensing images can be interpreted to recognize objects and elements presented in the form of thematic maps [14]. Remote sensing developments such as the band or channel and high sensor can describe geomorphological forms like relief and shape of the earth's surface [12]. Landsat 8 image is an image sensor that widely used today, consist of 7 bands. Bands 1-5 and 7 have spatial resolutions up to 30 meters and band 6 up to 60 meters. Bands 1, 2, and 3 are the visible spectrum, bands 4,5 and 7 are the infrared spectrum and band 6 is the thermal infrared spectrum [10].

This research aims to identify the development of landform and flow patterns at Pringkuku's karst region, the transition area, where the morphology of karst began to develop toward the western part of Gunung Sewu Karst region. The location of thin research is in Pringkuku, one of the sub-districts at Pacitan, East Java (figure 1).

II. Material and Method

Research methods are including landform interpretation based on Landsat 8 image and slopes value based on SRTM image then field checks. Primary data consists of landforms classification, slopes classification, and joints data as structural geology data. Secondary data consisting of RBI map with a scale of 1: 25,000 and geological map with a scale of 1: 100,000. Data analysis was done by comparing the data from image interpretation result and observation data in the field. The results of the interpretation used to divide the landform unit in Pringkuku.

The landform analysis in this study consists of three steps, including image interpretation, GIS analysis and joints data analysis with stereographic projection. Image reinforcement using bands 5, 6 and 7 of Landsat-8 image combination in the red-green, red and blue (RGB) channel arrangement. Bands 5, 6 and 7 are the infrared spectrum; that combination will produce composite images with pseudo color. This composite image is sensitive to lithology type changes so it can identify lithology distribution [3] [8]. Geological and geomorphological conditions at Pringkuku interpreted by visual observation of Landsat 8 image. Characteristics of fault structures can be revealed with the help of Landsat 8 images that have multispectral sensors. Landsat 8 multispectral image is good enough to be used as data in delineating the structural alignment automatically. The results of automatic delineation are revisited visually on the SRTM DEM to determine the alignment, which is a fault [2]. The morphological form of tectonic activity or karstification can be identified from the typical elongated or conical forms. Karst landform can be identified by the identification of cone-shaped hills, the presence of dolina and karstification products such as appearing springs and disappearing surface streams. Regional topographic data from SRTM image is required for landform analysis using GIS. Topographic data is used for interpretation of river branches and the presence of intermittent rivers, it's done to obtain the stream pattern that develops in the research area. Joints data analysis was added to describe the faults and tectonic processes that develop at the karst landform.

In this research, identification, and classification of landform based on van Zuidam landform classification. The determination of the landform's unit is based on three important aspects i.e. morphometry, morphography, and morphogenetic aspects. Morphography is landforms identification based on the distance between contours. Morphometry is a quantitative assessment of landforms based on slopes calculation and elevation. Morphogenesis is landform unit classification based on formation history, landform development and the processes that occur in it [17]. The boundary of landform unit obtained from analysis results involve interpretation of hue, texture, shape, pattern, location, and association based on composite image 567, ridge, and flow pattern, slope value interpretation by GIS analysis and stereography projection analysis from processing joints data. The combined analysis can identify the faults or lithologic differences that developed in the study area.

III. RESULT AND DISCUSSION

Visual observations of Landsat 8 images are to identify the karst hills in the research area. The morphology in the western part of the research area has a lineament form of the cone hills characteristics with east-west trending while the morphology in the eastern part of the research area has complex valleys form characteristics.

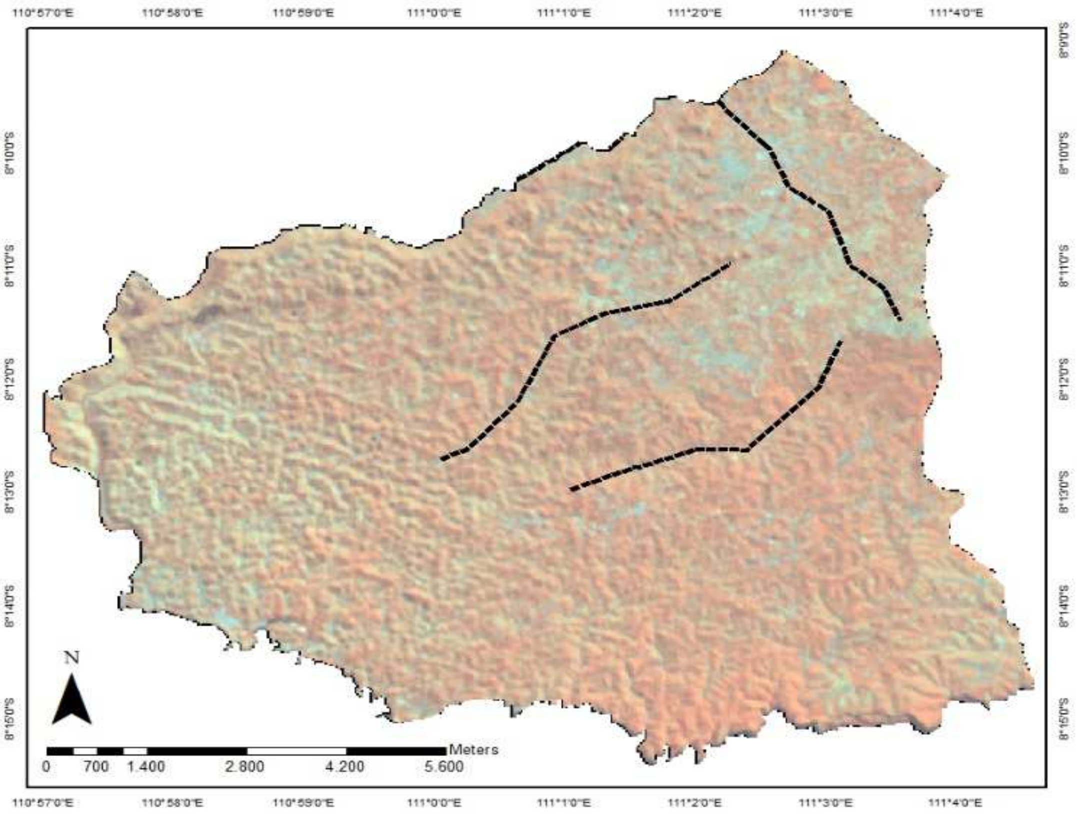

Fig. 2 Color composite result of 567 bands from Landsat 8 image and lineament interpretation (black dotted lines).

Landsat 8 image interpretation can identify some lineament patterns, lithology characteristics and lithology distribution based on hue, texture, shape, pattern, location and association (figure 2). Color composite RGB 567 shows the morphology of the research area in each lithology formation. The clastic limestone of Oyo formation recognized has a lighter hue and smoother texture; in the south, this formation has a dark hue, coarse texture, and solid color. Then the reef's limestone of Wonosari formation recognized has a dark hue, coarse texture, mixed with Oyo formation in the west and still has a coarse texture.

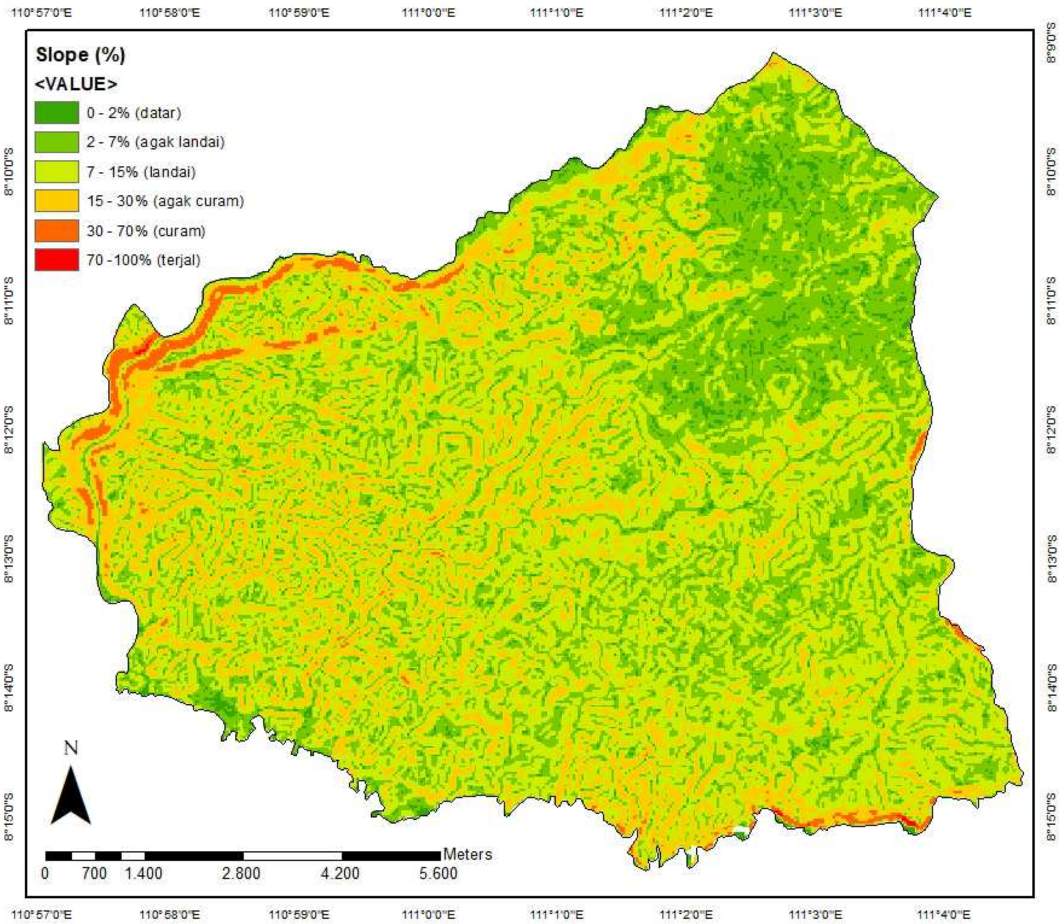

Fig. 3 Slope value of Pringkuku district, Pacitan.

Based on morphometry analysis, the slope of the dominant slope is gently sloping with slope dominant of 2-7% at the northeast, rather steep with slope dominant of 15-30% at the southern and southwestern of Pringkuku, and steep with slope dominant more than 30% at the western of Pringkuku. Areas with gently sloping predominate in the northeastern of Pringkuku, areas with slightly a steep slope predominating in the southern and southwestern of Pringkuku, and areas with steep slopes are found in the western Pringkuku around Kali Klanden (figure 3).

Morphogenetics is a process that influences the formation of landforms, to find out the influential process, the researchers compare the developing river flow patterns, their relationship with the developing geological structure and the lithology that composes the research area. The land area of Pringkuku area is heavily influenced by endogenous processes which include constituent lithology which has different characters in the west and east, composed of reef limestones which dominate in the west and clastic limestones which dominate in the east, then the presence of tectonic controls in the form of two faults the shear that occurs in the clastic limestone rocks are the strike-slip fault in Kali Barong and Ngadirejan River.

A. Flow Pattern

The flow pattern in the research area can be identified by analyzing the valley pattern of the topographic map and SRTM image.

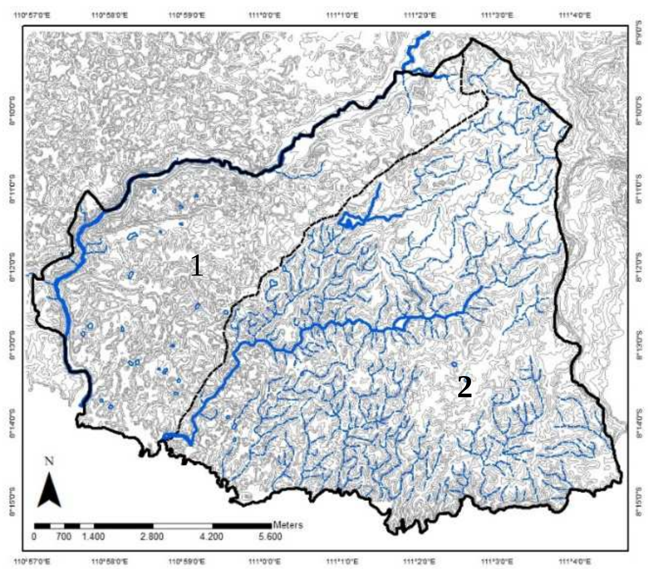

Fig. 4 Flow pattern in the research area (1) multibasinal and (2) rectangular.

The flow pattern interpretation results are divided into two parts; the first is the multibasinal flow pattern in the western region of Pringkuku, this flow pattern is characterized by a discontinuity or suddenly disappears rivers on the surface. This flow pattern controlled by the dissolution of limestone as its constituent lithology and identified by the discovery of lakes, luweng and springs. The second is a type of rectangular flow pattern located in the eastern region of Pringkuku. This pattern has angular and curved characteristics of the confluence of the main river and its brook, typically controlled by structures or faults that have a slope angle, a non-recurring layer of lithology and often showing discontinued flow pattern (figure 4). The rectangular pattern in the eastern region of Pringkuku controlled by strike-slip faults. Some indications, such as joints on deformed rocks and waterfalls on the surface rivers were found during field observations. Two types of faults control the flow direction of the rectangular pattern in the eastern region of the study area:

1) Ngadirejan dextral strike-slip fault: This fault is in the northeastern of the research area. Ngadirejan dextral strike-slip fault is determined based on joints data processing at the intermittent river in Ngadirejan (observation station 1 and 2) and interpretation of the ridge and valley lineament using SRTM image. The results of joints data processing show the strike-slip fault type, stereonet projections show that the most significant force of σ1 relatively has northwest-southeast direction, while the holding force is σ2 is in the vertical plane so that the force generated by σ1 produces a strike-slip fault. Dextral movement can be evidenced by the pattern of broken off the ridge in SRTM image (Figure 5). The lineament of the ridges and the valleys has a dominant direction of N75^{o}E.

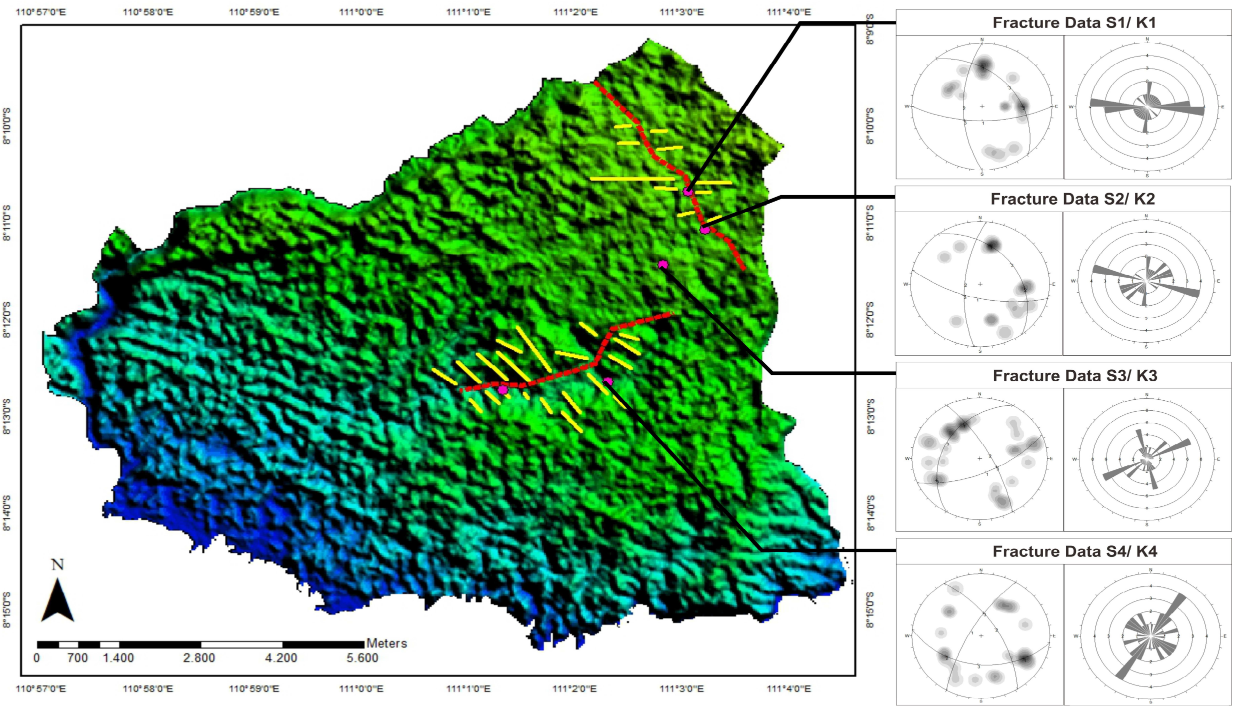

Fig. 5 Joint/fracture data analysis in stereography projection, lineament analysis (red line) and shifting ridge analysis (yellow line) based on SRTM image.

Straightness shift is interpreted as a shift caused by the presence of a fault structure, which is a dextral strike-slip fault. The result of processing stereographic projection is known that the most prominent force σ1 has a northeast-southwest direction with the N5^{o}E direction and the fault plane has a relative direction N140^{o}E. Ngadirejan fault is classified in *the first order* based on the Moody and Hill fault system modeling because the most extensive compression force erodes at a 45^o angle range.

2) Barong sinistrality strike-slip fault: This fault is in the eastern of the research area. Barong sinistrality strike-slip fault is determined based on joints data processing at the Barong river (observation station 3 and 4) and interpretation of the ridge and valley lineament using SRTM image. The result of joints data on stereonet shows the strike-slip fault type, stereonet projections show that the largest force of σ1 is relatively northwest-southeast, while the holding force of σ2 is in the vertical plane so that the force generated by σ1 produces a strike-slip fault. The direction of σ1 and σ3 are relatively horizontal to σ2. Besides, some indicators show deformation rock such as there a waterfall in the middle of Kali Barong and the outcrop of contact between the clastic limestone and reefs limestone. Sinistrality movement can be evidenced from the pattern of broken off ridge in SRTM image (Figure 5). The lineament of the ridges and the valleys has dominant direction of N130^{o}E. Straightness shift is interpreted as a shift caused by the fault structure which is a sinistrality strike-slip fault. The result of processing stereographic projection is known that the biggest force σ1 has a northwest-southeast direction with the N110^{o}E direction and the fault plane has a relative direction N75^{o}E. Barong fault is classified in the first order based on the Moody and Hill fault system modeling because the largest compression force is eroding at a 45^o angle range.

B. *Interpretation of Landform and Distribution*

The result of some aspects of the observation including slope value, flow pattern, slope shape, valley shape and ridge pattern, are used to divide the research area into two geomorphology units, namely:

TABLE I
CHARACTERISTICS OF GEOMORPHOLOGICAL UNITS IN THE STUDY AREA

Geomor-phology Unit	Color Symbol	Morfography			Morphometry			Morfography		
		Land form	Flow Pattern	Valley Form	Slope		Slope Class	Process		Constituent Material
					(°)	(%)		Endogenous	Exogenous	
Structural Limestone Hills Unit		Hills	rectangular	U - sharped	0 - 45	0 - 100	Gently sloping– rather steep	Structural	weathering, erosion	Classics limestone dominated, partly reef limestone
Conical Limestone Hills Unit		Hills	multibasinal	V	0 - 45	0 - 100	rather steep - steep	karstification, structural	weathering, erosion dominated	Reef limestone

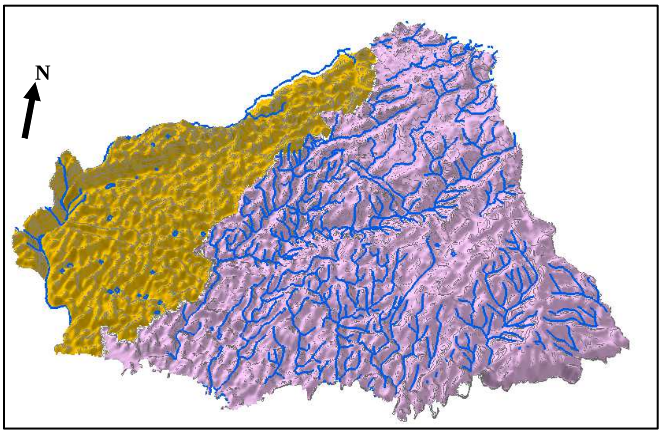

Fig. 6 3D shape of geomorphology unit in the study area.

1) Structural Limestone Hills Unit: Geomorphological units of structural limestone hills are scattered in the eastern of the research area, with a spreading area of 68.18% of the research area. This unit has an altitude of 0 - 455.04 asl, with a slope angle of 0 - 45^o and a slope percentage of 0 - 100%. The hill that composes this geomorphological unit includes the Pacitan Indah Hill (347 asl) and some dolina that compose are Tlogo Tumanagan, Tlogo Palem, Tlogo Gebang, Tlogo Pangilon, Tlogo Watu, Tlogo Asem and Tlogo Blue.

Fig. 7 Structural limestone hills unit (kali Barong Area)

The flow pattern that develops in this unit is the rectangular pattern. The rivers that compose this unit are including Kali Barong River, Kali Blue, and Kali Sebrok. The river flow has some varies directions, but it generally has northeast-southwest and west-east flows direction. The sloping form is convex relatively composed of hard rock composite materials. The valley form is a sharp U-shaped valley with lateral erosion process is higher than the vertical erosion. The lithology composed in this unit is mostly clastic limestone and partly reefs limestone with harsh rock conditions. The controlling factor of this geomorphology unit is the endogenous force of strike-slip fault. The area is used for residential and agricultural purposes.

2) Conical Limestone Hills Unit: Geomorphological units of conical limestone hills are scattered in the west of the research area, with a spreading area of 31.82% of the research area. This unit has an altitude of 0 - 432.01 asl, with a slope angle of 0 - 45^o and a slope percentage of 0 - 100%. The sinkhole/dolina that compose this geomorphology unit are Tlogo Winong, Tlogo Dokjero, Tlogo Dokpucung, Tlogo Mati, Tlogo Melian, Tlogo Balong, Tlogo Sumur, Tlogo Kuan and Tlogo Dokbalong.

Fig. 8 Conical limestone hills unit (Tlogo Dokbalong)

The flow pattern that develops in this unit is the multibasinal pattern. The vertical cave or luweng was found in this unit that indicates the existence of sub-surface river that formed this unit. The luweng that composes this geomorphology unit are Luweng Jomblang, Luweng Winong and Luweng Tanggung. The flow of the underground river is estimated to have the same direction as the surface rivers in the east of the research area with northeast-southwest and west-east flow directions. The sloping form is convex relatively composed of massive rock composite materials. The valley form of karst morphology is sinkhole or doline form. The sinkhole or doline is a morphological characteristic of dissolved limestone. Reefs dominate the lithology composed in this unit with harsh rock and massive conditions. The controlling factor of this geomorphology unit is the exogenous force of weathering and dissolution. This area is used for residential and agriculture.

IV. Conclusions

Color composite RGB 567 can identify the morphology and lithology of the research area, morphology of alignment of the cone hills composed by reefs limestone of Wonosari formation which has dark hue and coarse texture develop at the western part of the research area, morphology of complex valleys composed by clastic limestone of Oyo formation which has lighter hue and smooth texture developed at the eastern area.

The flow pattern is divided into two parts; the first is the multibasinal flow pattern in the western Pringkuku and the rectangular flow pattern in the eastern Pringkuku. The rectangular flow pattern was controlled by the strike-slip fault that passes through the east of the research area, ie the Ngadirejan dextral strike-slip fault in the northeastern of the research area and the Barong sinistrality strike-slip fault in the center till the east of the research area.

The geomorphological unit in Pringkuku consists of two units, that are the structural limestone hills unit and the conical limestone hills unit. The structural limestone hills unit is scattered around 68.18% in the eastern of the research area, while the conical limestone hills unit is scattered around 31,82% in the western of the research area.

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