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LANDSCAPE MODEL OF THE TANJUNGPANDAN GRANITOID, BELITUNG DISTRICT, BANGKA BELITUNG ISLANDS PROVINCE, INDONESIA

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ABSTRACT: The Tanjungpandan granitoid landscape reflects a landscape model influenced by interaction of granite characteristics, fractures, sea-level fluctuations, and climate. This study aims to reveal those interactions quantitative and qualitatively, in particular, the separation between regolith and resistant granite masses. The location of the research area is in Tanjungpandan, Belitung District, Bangka-Belitung Islands Province, Indonesia. The method applied in this research is field observation and laboratory works consisting of petrographic analysis and geochemical analysis with the XRF method to determine the rock properties which is affected to the rock resistance level. In addition, fractures observation was carried out to determine the fracture pattern and dimension. The objective of the research analysis is to reconstruct the role of the interaction between granite and fracture characteristics with the climate change and sea-level fluctuations which are external factors that play a role in rock weathering which in turn produces granite landscape models. Based on classifications [3] the landscape of Tanjungpandan granite consists of inselberg, bornhardts, nubbins, castle koppies, pillars, and etches. Other features are ranges of minor granite boulders, flare slope, grooves, valleys, and aplite embankments. The vertical and sheet fractures are very dominant affected by differential weathering below the surface, compared to the granite properties which are less significant. The landscape of Tanjungpandan granitoid is very typical due to its genesis which involved sea-level fluctuations during the Quaternary, and tectonic-magmatic of island arcs.

Keywords: Tanjungpandan granitoid, Landscape, Petrographic analysis, Fractures analysis, Tectonic-magmatic

1. INTRODUCTION

The Tanjungpandan granitoid area in Belitung Island is a tourist destination with diverse geological, cultural and biological diversity. The Government of the Republic of Indonesia assigned the area as Belitung National Geopark national and pursues to become the UNESCO Global Geopark (UGGp) and member of Global Geopark Network (GGN). Geodiversity defines as a diversity of rocks, minerals, fossils, geomorphology, soil, and topographic and hydrographic elements [6]. According to [12], geomorphological diversity includes a) Geoheritage: geodiversity, geomorphology, rocks, minerals, and tectonic; b) surface processes: geomorphological dynamics, process complexity, climate variations; and c) history: geomorphological evolution, chronological diversity, tectonic history, and climate.

Research on the landscape of granite has been widely carried out by previous researchers, such as [2, 3, 10, 13, and 15] in subtropical and desert regions of Australia, Africa, America, Europe and Asia.

The landscape of granite classify into major and, minor forms [2, 3]. The major granite range consists of inselbergs, bornhardts, etch, nubbin and castle koppies. While the minor forms consist of: weathering, constructive and tectonic forms; and convergent and divergent pressure properties. The size, shape, and type of the granitoid landscape are influenced by various factors: magma emplacement, tectonics, lithology, and fracture. The Tanjungpandan granitoid landscape is part of geo-diversity that reflects the effects of rock characteristics, fractures, sea-level fluctuations, and climate change. This study aims to determine the Tanjungpandan granitoid landscape model.

The research area is located in Belitung Regency, Bangka Belitung Islands Province. The study was conducted in a location of 1025 hectares, covering the Tanjungpandan granitoid described by [1] (Fig.1).

2. GEOLOGY OF THE RESEARCH AREA

The research area according to [1] is occupied by (from old to young)**:** Kampit Kelapa Formation is light gray–reddish color, composed of meta-claystone alternated with slate, mudstone, siltstone, chert, cassiterite, and galena; sedimentary structures of graded bedding, cross-bedding, ripple marks, and parallel lamination; with radiolarian fossils, indicated that deposited in the marine environment.

Tajam Formation is greenish-white color, fine to coarse-grained, sub-rounded-rounded, composed of quartz meta-sandstone inserted by siltstone; with graded bedding and parallel lamination sedimentary structure. It contains a tin bearing quartz vein. Siantu Formation, dark green colored, aphanitic texture, composed of basalt lava and volcanic breccias, compact, indicate pillow lava structures. The main minerals are plagioclase and pyroxene and secondary minerals are chlorite and calcite. Basalt-fragmented breccias, size 5-30 cm, sub-angular-sub rounded, deposited in the marine environment. Those formations are Perm-Carbon in age and inter-fingering in their depositions. Tanjungpandan granite intruded the Kelapa Kampit Formation, Tajam Formation and Tanjung Siantu Formation [1]. The uppermost succession is alluvial deposits which consist of gravel, sand, silt, clay, and coral (Table 1).

Tanjungpandan granitoid, light gray in color, medium to very-coarse even extreme coarse crystal, porphyritic-phaneritic, foliated, composed of quartz minerals, feldspar, plagioclase, biotite, and hornblende.The granitoid is differentiated into three types: syenogranite, monzogranite, and syenite. Tin mineralized to form greissen and fracture vein has occurred within the granitoid. Based on K-Ar dating the age is 208-245 million years. The geological structure of the study area consists of east-west and northeast-southwest faultings, and north-south trending axes fold. It also consists of faults with northeast-southwest, northwest-southeast and north-south trending (Fig.2).

3. METHODOLOGY

The research method was carried out by observing rocks to determine rock resistance through petrographic analysis to identification of textures and minerals, also XRF geochemical analysis method by Laboratory of PT. Intertek Utama Services, Indonesia, for the identification of the chemical constituents of minerals and rocks, so that granite genesis are known. Fractures observation by rose diagram and statistic method were made to determine the fracture pattern and dimensions. Furthermore, reconstructing the relationship between granite properties and fracture characteristics with external factors of climate change and sea-level fluctuations based on the results of previous studies will produce weathering and landscape models of granite (Fig.3). The study used topographic maps of 1: 100,000 and 1: 50,000 scales, Geological Map Sheet of Belitung of 1: 250,000 scale and Geographic maps of 1: 250,000 scale, and Shuttle Radar Topography Mission (SRTM) - Digital Elevation Models (DEM) imagery.

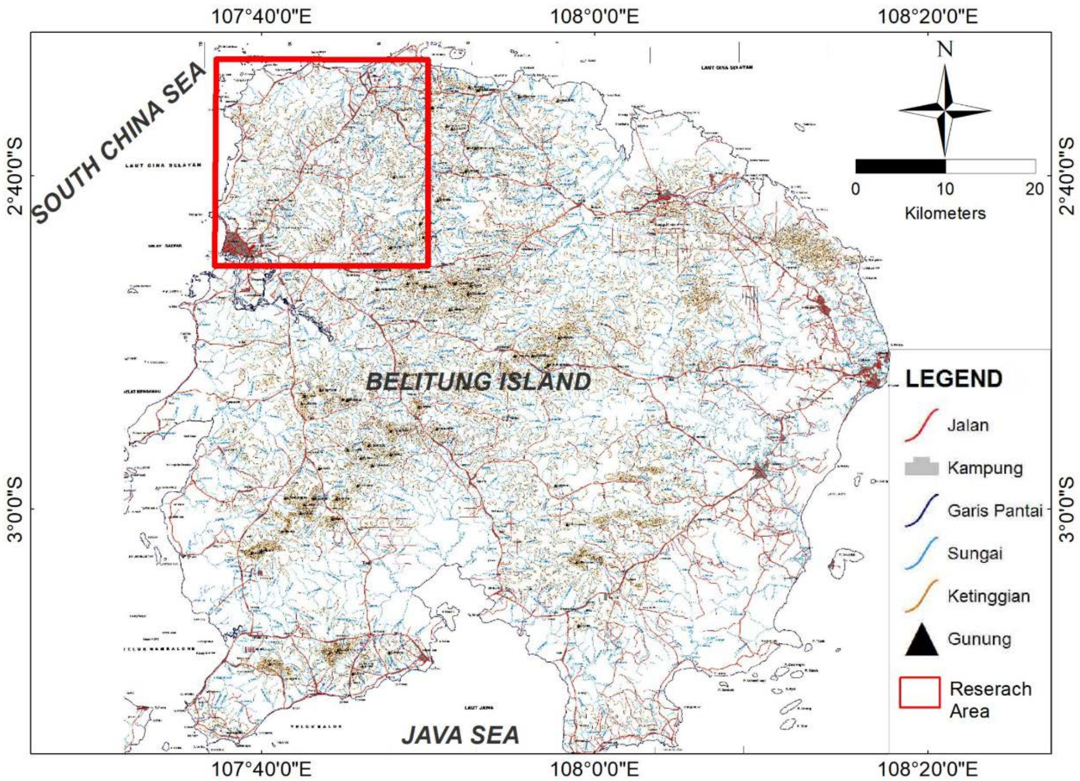

Fig.1 Location of the research area

Table 1 Stratigraphic columns of the study area modified from [1]

Ages	Periods	Episode	Sedimentary	Volcanic	Plutonics	Regional correlation
Cenozoikum	Quarternary	Holocene	Alluvium			Aluvium
		Pleistocene	Erosional surface			Carbonaceous sand
	Tertiary	Pliocene				
		Miocene				
		Oligocene				
		Eocene				
		Paleocene				
Mesozoikum	Cretaceous				Unconformity	
	Jurasic				b, a, c	Tanjungpandan Granite
	Trias		Unconformity			
Paleozoikum	Perm		Meta-sandstone			Tajam Fm.
	Carbonaceous		Meta-claystone	Meta-volcanics		Tg. Siantu Fm. Kelapa Kampit Fm.

Note: (a) Syenogranite, (b) Monzogranite, (c) Syenite

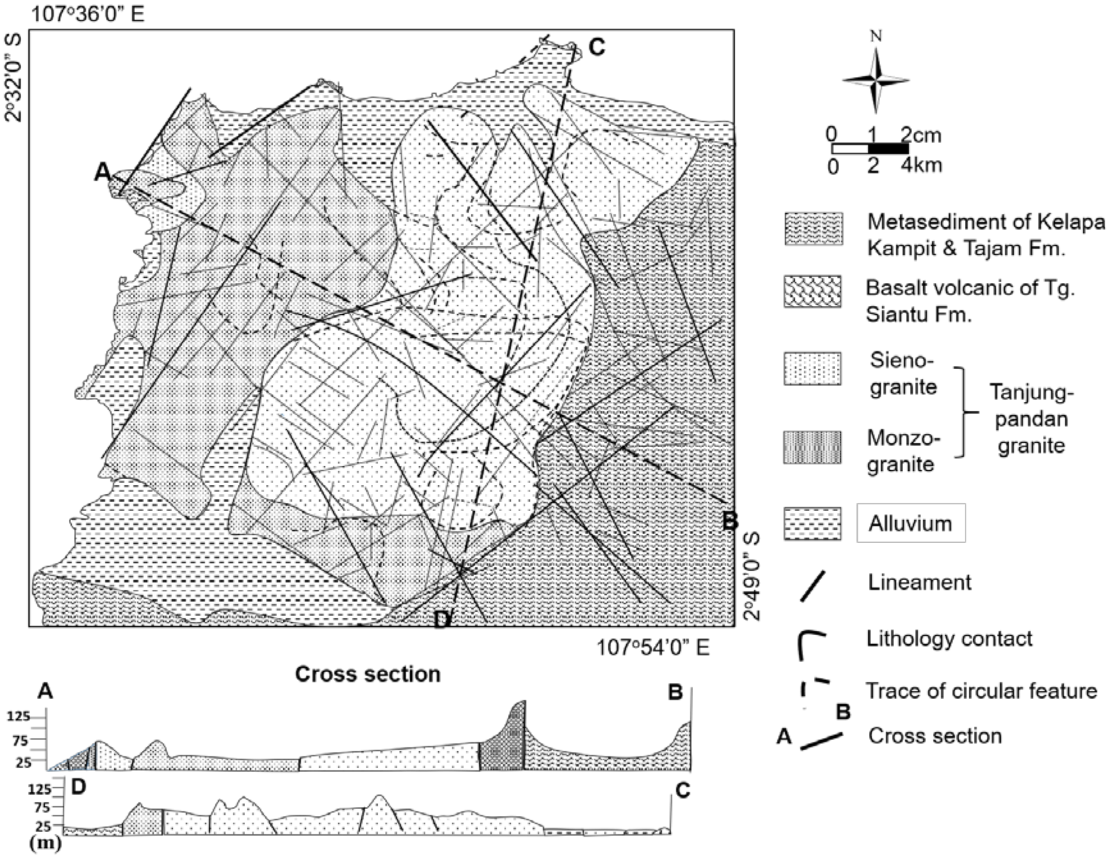

Fig.2 Regional geology of the research area (Modified from [1])

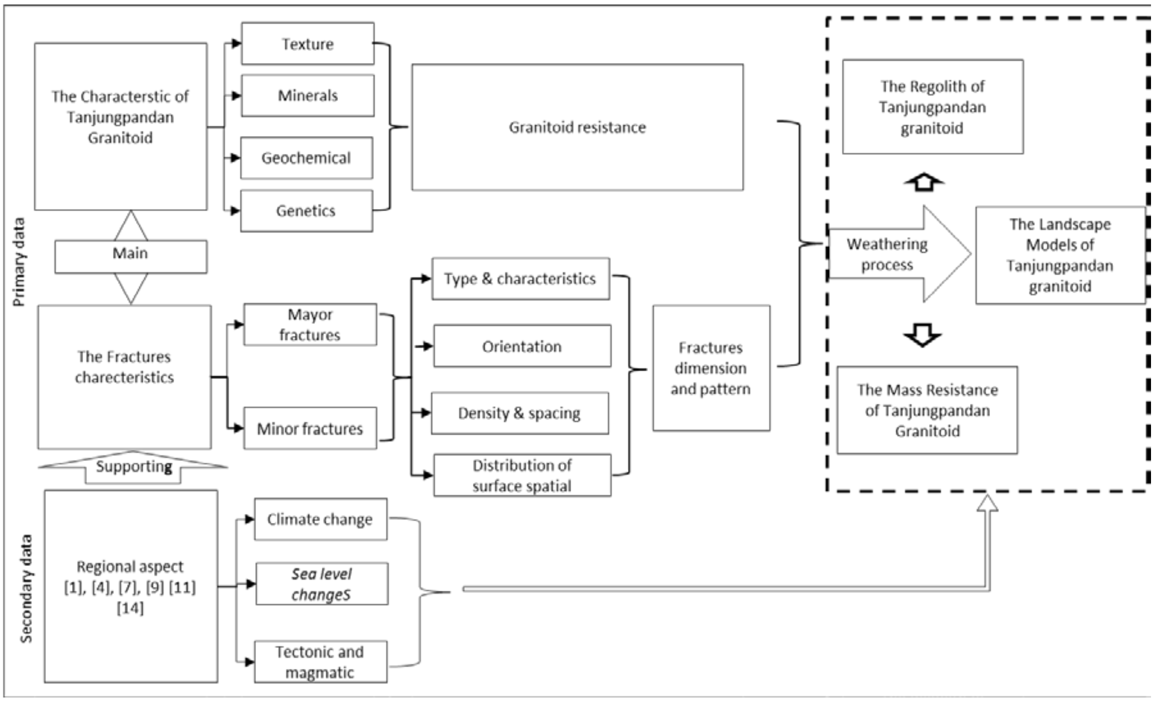

Fig.3 Concept of the landscape research of the Tanjungpandan granite models

4. RESULTS AND DISCUSSION

4.1 Granitoid Properties

Based on genetic characteristics of the granite it was found that syenogranite and monzogranite are easily weathered compared syenite. Grain sizes of syenogranite, monzogranite and syenite are more resistant to form granitoid masses as boulder and weathering front. Microtexture and structure of syenogranite, syenite and monzogranite are less resistant and thus easily weathered. The higher composition of plagioclase and biotite in syenogranite and monzogranite caused easier weathered. Syenite contains higher K-feldspar. Mineralization in syenogranite and monzogranite is more intensive, high density with narrow spacing with high permeability and porosity are easily entered by weathering agents.

Partially differentiated syenogranite and monzogranite due to syn-collision resulting in uneven chemical composition, mineral, and texture. This rock composition produced the morphology of hills with narrow ridges, steep slopes and ellipsoid shapes which are easily weathered. Syenite spreads narrowly at the edge of the syenogranite and monzogranite. Therefore it insignificantly influenced weathering in the formation of Tanjungpandan granitoid landscapes.

4.2 Dimensions and Fracture Patterns

Major fracture types include faults, intrusion traces, geological structures, and rock layers. Faults in the study area are northeast-southwest, northwest-southeast, west-east, and almost north-south. The distribution of lineaments and intrusion contacts on the surface forms orthogonal patterns, parallel and elongated, open and discontinuous which form segments of varying sizes (Fig.4 and 5). Syenogranite and monzogranite are interpreted as batholiths which are both separated by north-south lineament. In the middle part of syenogranite and monzogranite contain intensive mineralization forming the plain and valleys bounded by silicified zones and non-mineralized granite producing narrow hills with steep slopes.

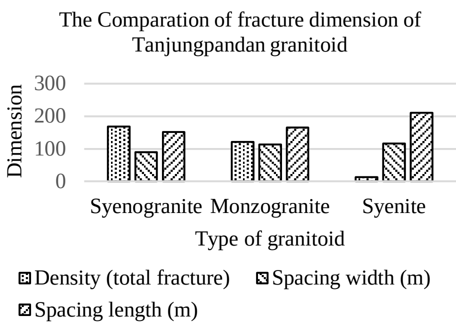

Fig.4 Dimension of mayor fracture

Minor fractures are found in the forms of crushed, tensile, sheet, orthogonal, diagonal, vein and aplite. The north-southeast-southeast oriented crushed fracture and the surface-northeast northeast-southwest fracture form orthogonal and triangular patterns (Fig.6).

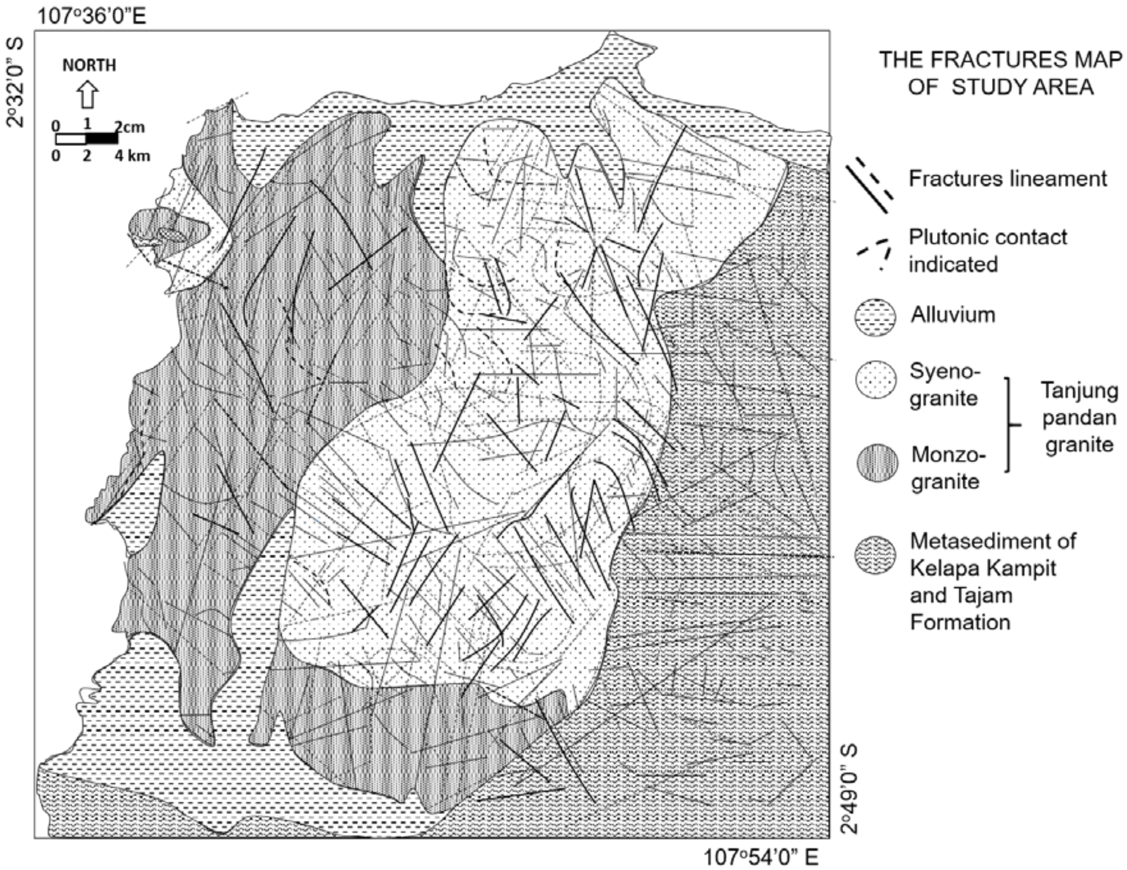

Fig.5 Distribution and pattern of major fractures plotted in the Geological Map

Fig.6 Vertical fracture that develops in granite

The fracture in syenogranite is the longest (373 cm) compared to other granitoid; tightest spacing is on syenite (12 cm) and monzogranite (13 cm) and syenogranite (26 cm); and the highest monzogranite density (131 fractures per m^2), compared to syenogranite (36 fractures per m^2) and syenite (24 fractures per m^2) (Fig.7).

4.3 Granitoids Fractures

The Granitoid fractures are formed due to exfoliation resulting in sheet, orthogonal and diagonal fractures. The sheet fracture has a slope of 18^0 or almost parallel to the topographic slope (Fig.8 and 9), while the vertical and diagonal joints intersect almost perpendicular to the topographic surface (Fig.10).

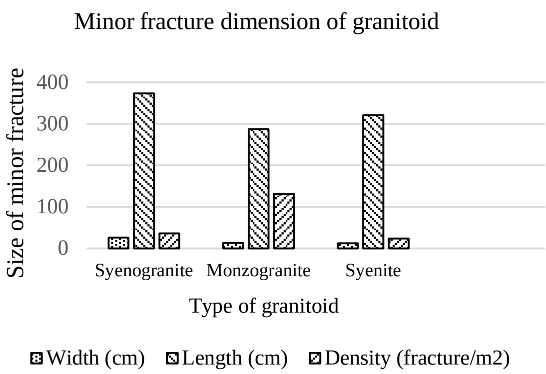

Fig.7 Dimension of minor fracture

The fracture characteristics affect the intensity of weathering solution entering the rock determining the size and shape of the resistant granite landscape. Syenogranite and monzogranite have high major fracture density and narrow spacing causing the high level of destruction, weathering and erosion to the subsurface resulted in thick regolith with corestone and a plain topography in the valley (Fig.11).

Fig.8 Sheet fractures in granitoid

Fig.9 Sheet fractures in monzogranite found at Tanjung Kelayang

Fig.10 Vertical (orthogonal) fractures in granitoid

4.4 External Tertiary-Quaternary Aspects

Since the end of the Tertiary-Quaternary, the study area was affected by climate change with the changing characteristics of the dry-rainy season and high humidity causing the development of micro-organisms and biota very quickly, intensive chemical reactions, The weathering process of biology, chemistry, and physics, therefore, was intensive; sea-level changes reaching 100 m below and above sea level [11,14] (Fig.12) and stable tectonic conditions, causing more intensive denudation activities which was characterized by a) Coastline abrasion producing beach terraces and land terraces, b) increased supply of weathering solutions, c) Changes in ground-level elevation, d) Intensive differential weathering, e) thick regolith layers and thick alluvial and/or colluvial deposits, f) The weathering front was exposed so that chemical and biological weathering occurred in minor fractures.

4.5 Weathering

Based on the distribution pattern, weathering in the study area is controlled by the pattern and dimension of the fracture and granite resistance that forms a basin or valley filled with alluvial and colluvial deposits, such as: that found in Tanjungpandan in the west - southwest, Tanjung Binga-Kelayang in the northwest and Tanjung Binga-Sijuk in the north.

Types of granitoid weathering in the study area are divided into fresh rock, partial weathered, residual weathered, and perfectly weathered. The research area is a landscape of denudation with the spread of light weathered rock in the southeast, east and northeast. Weathered granitoid is partly the largest area in the southeast, east, northeast, and northwest; residual weathered granitoid spreads in the southwest, west, north, and east; and perfectly weathered granitoid in river valleys, plains and coastal areas (Fig.13).

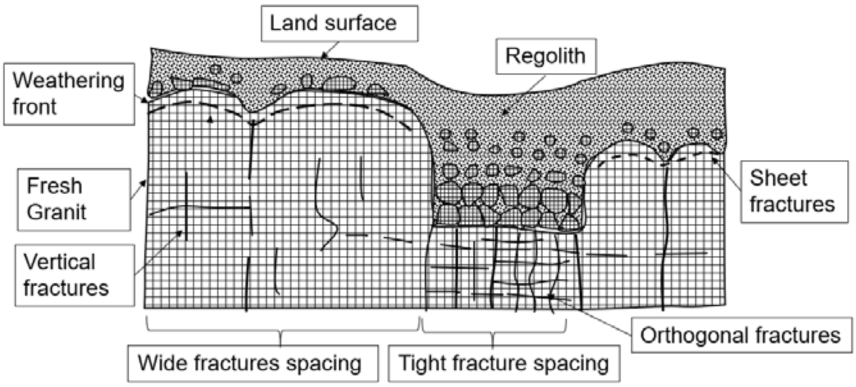

Fig.11 The Illustration of the relation between fracture density and spacing to weathering [2]

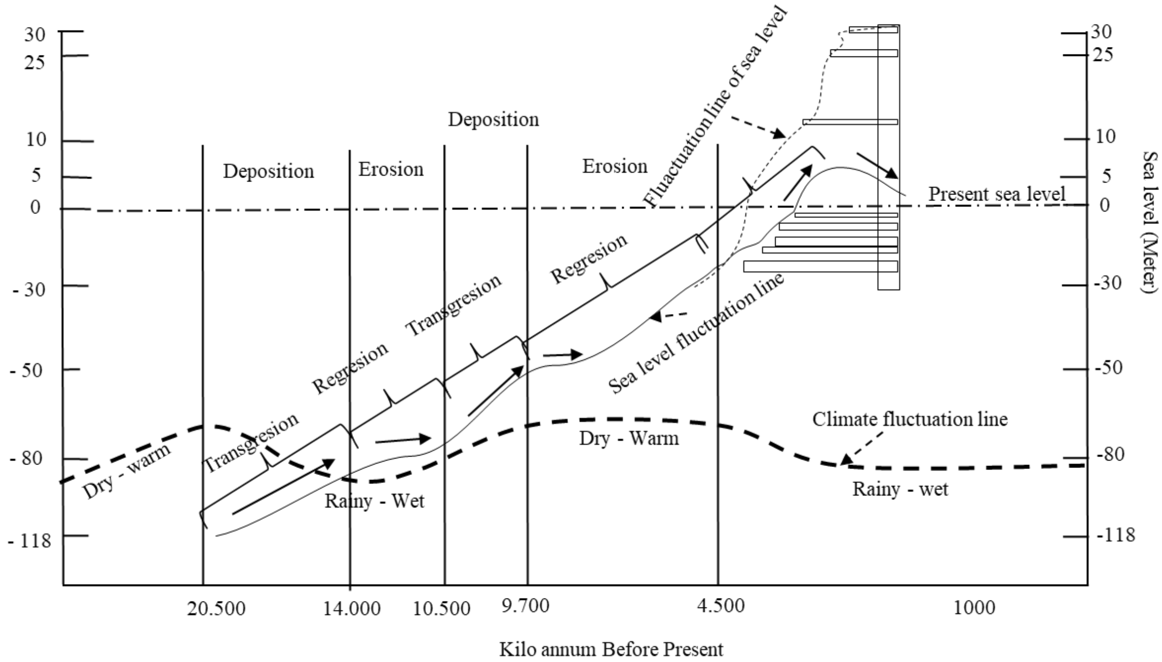

Fig.12 Relationship of the Quartenary climate, sea level change and tectonic modified from [9, 11, and 14].

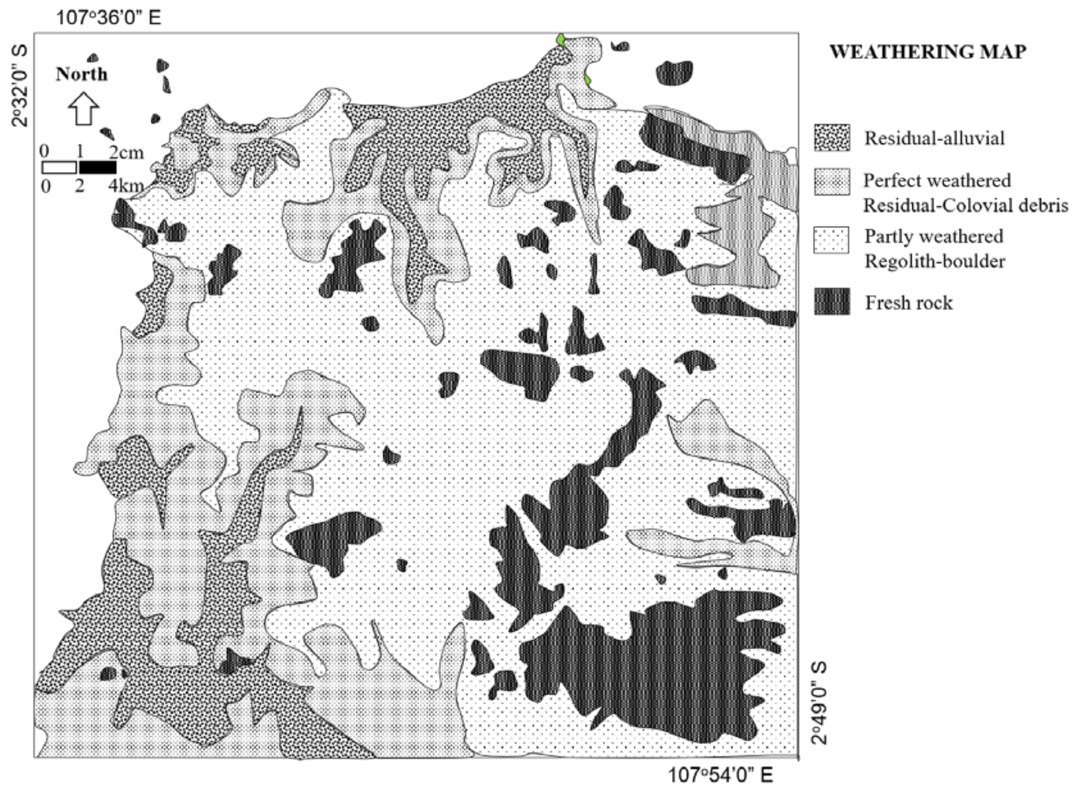

Fig.13 The Weathering map of the study area

4.6 Erosion and Deposition

Erosion and deposition are the mechanical or physical processes of destruction and transport of rock material deposited into a basin or valley. Media erosion, transportation, and deposition by water flow which is affected by fluctuations in sea levels due to tectonics as a regression that causes base level steep topographic, weathering front exposed and weathering occurs at the surface; and transgression causes subsurface weathering, deposition. Weathering front is closed, regolith and Alluvial deposits become thicker and the process of sloping topography. Sediment type is debris flow with poorly sorted material and fine-lump size. Upward and distal turn smooth form alluvial fan (Fig.14).

4.7 Landscape in the Study Area

Landscape in the study area can be divided into steep hills, medium hills, low hills, solitary hills, and valleys (Fig.15). The slope of steep hills is 50^0-80^0, height of 250-600 m above sea level, occupied meta sediment and granite, and radial drainage pattern, with a degree of young erosion. Medium hills with a slope of 20^0-45^0 and altitude of 100-200 above sea level, occupies granite, trellis-rectangular drainage pattern, with moderate-mature erosion rates. Weak rolling hills, slope 7^0-20^0, altitude 15-60 m above sea level, occupies granite, meta-sediment, and alluvium, dendritic drainage patterns, rectangular and parallel with the level of mature erosion. A solitary hill with a slope of 40^0 - 80^0 is occupied granite, radial-patterned with a level of young erosion. Plain and valley slope 4^0-7^0 height 5-25 m above sea level, occupies alluvial dendritic - parallel drainage pattern with the level of erosion of mature to old stadium (Table 2).

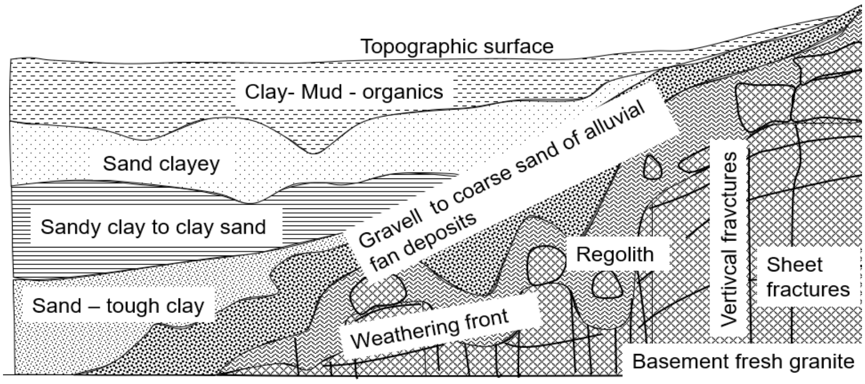

Fig.14 Illustration of the weathering models of granite, regolith and alluvial deposit.

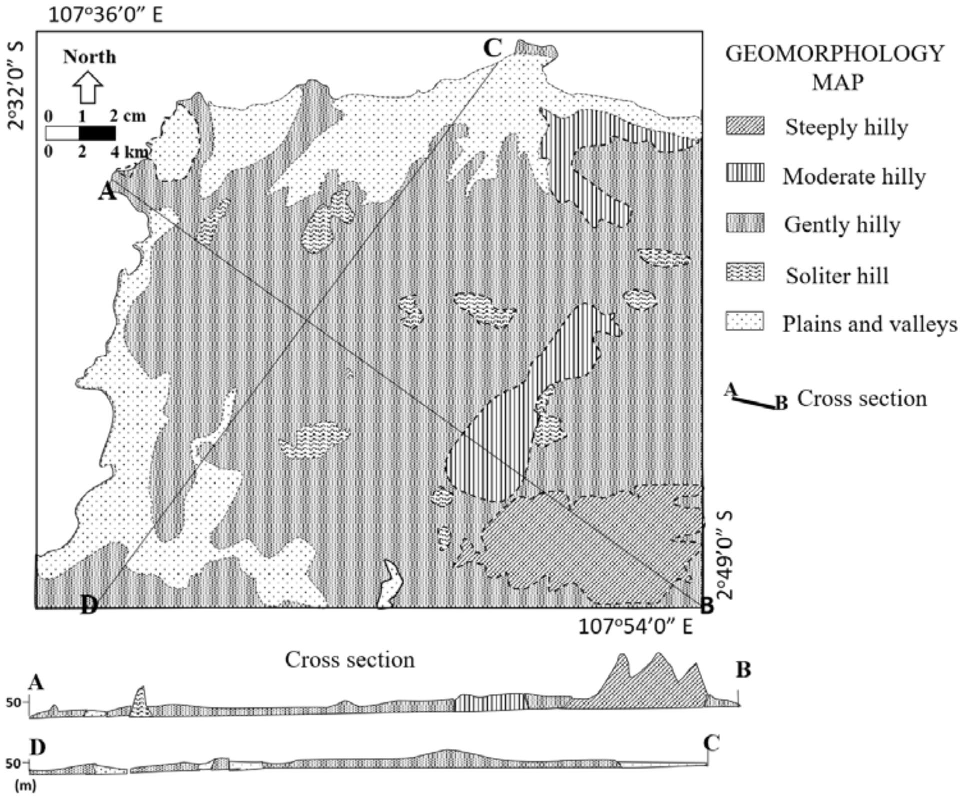

Fig.15 Geomorphology map of the Study area

Table 2 Geomorphology of the study area

Morphology unit	Slope (^{0})	Elevation (meter above sea level)	Lithology	Drainage pattern
Steep hilly	$50^0 – 80^0$	250 – 600	Meta sediment and granite	Radial
Moderate hilly	$20^0 – 45^0$	100 – 200	Granite	Trellis-rectangular
Gentle hilly	$7^0 – 20^0$	15 – 60	Granite, meta sediment, alluvial	Dendritic-rectangular, parallel
Soliter hill	$40^0 – 80^0$	50 – 80	Granite	Radial
Plains and valley	$4^0 – 7^0$	5 – 25	Alluvial	Dendritic-parallel

4.8 The Landscape of Granitoid

In research, the classification of granitoid landscapes refers to [2, 3, and 15]. Differences in naming, size and shape due to differences formation influenced by granitoid genetic makeup, fracture patterns and dimensions, climate and sea-level fluctuations.

4.8.1 The major landscape of granitoid

The major landscape of granitoid found in the study area includes inselberg, bornhardts/domes, nubbins, and pillars and etches. The following description describes each of these granitoid landscapes.

Inselberg. Inselberg landscape locates in the southeast, south, and north of the study area were found in monzogranite hills that extend and stands out from the surrounding area in the form of a plain with steep slope boundaries (Fig.16).

Fig.16 Nubbin (front) with background inselberg (back) in southeast of Tanjungpandan

Bornhardts.Spans of bornhardts or oval domes are found north of Tungkusan and Perawas, measuring 100 m wide by 200 m long and 30 meters high from the average ground surface, blackish-brown in color (Fig.17), covered with fungus and algae, massive, medium to steep slope, barren, very rough surface because biotite and plagioclase decays and dissolved leaving quartz and potassium feldspar. Bornhardts are formed in monzogranite, coarse-grained - very coarse, porphyritic-phaneritic texture. Towards the edge of the body bounded by an upright spacing of 5-10 meters and a fractured spaced sheet > 5 meters. Minor morphology is in the form of gutters, grooves and aplite embankments.

Fig.17 Granitoid dome to the north of the Perawas

According to [13], bornhardts are formed in 2 stages namely the stage of weathering below the surface due to differences in rock resistance and step erosion of regolith outcropping the weathering front. Bornhardts can develop into etches, nubbins and castle koppies (Fig.18).

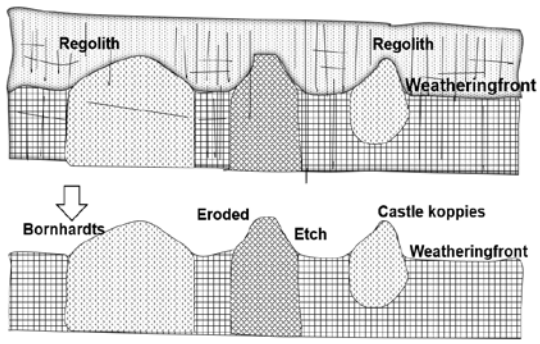

Fig.18 The mechanism of bornhardts, etch and castle koppies formation according to Twidale, 1998.

Nubbin. The landform of nubbin in the form of a rectangular block measuring 0.3 - 5 meters, scattered in an irregular position but collected into elongated hills (Fig.19). Nubbins are formed in syenogranite, brownish-yellow, coarse-grained - very coarse, porphyritic-phaneritic, caused by sheet fracture dominant (Fig.20).

Fig.19 The morphology of the nubbins to the north of the Tungkusan

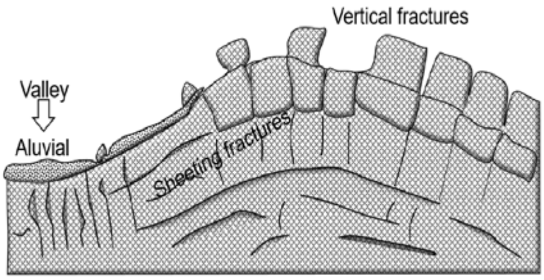

Fig.20 The schematic of the formation of the nubbin

Castle koppies. Castle koppies landform are vertical shaped boulder upright side by side forming gaps so close together, found on the coast of Tanjung Tinggi (Fig.21). Morphology is formed on syenogranite, light-yellowish gray, coarse-grained, porphyritic and xenolithic, compact, massive, hard, gneissic, which has weathered along the vertical fracture to the subsurface. Vertical fractures are more dominant than sheet fractures, with 3-7 meters fracture spaces, and 3 - 10 fracture densities per meter. Some minor morphologies that have developed include flares and grooves.

Fig.21 Castle koppies in Tanjung Tinggi.

Etch. Etch landform is found in the Perawas area, in the form of ellipsoidal with 50 meters length, 35 meters width and 30 meters height from the surface of the foothills and steep slopes to vertical (Fig.22). At the top, there is a rounded boulder called a balancing rock 8 meter in diameter with a height of 6 meters (Fig.23). This landscape is found in syenogranite, gray, and brown to black, medium-coarse, porphyritic, massive, compact and hard. The rocks are intruded in aplite, light gray, aphanitic, compact, hard, 7-10 cm thick. Morphology is formed by sheet and vertical fractures where vertical fractures are more dominant. Upright spacing of 10-20 meters and fracture sheets of 4-6 meters. Minor morphologies include flare slope, grooves, and aplite embankments.

Fig.22 Dome of the ellipse with balancing rock, at Perawas central part of Tanjungpandan granitoid

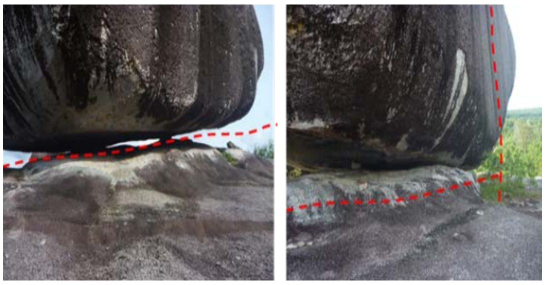

Fig.23 Morphology of balancing rock in Perawas, central part of Tanjungpandan granitoid

Pillar. The single pillar landform in the Kandis area, vertical shape on a dome with 7 meters height and 4 meters width, blackish brown, covered with mold and rough surface (Fig.24). In Tanjung Kelayang offshore pillars are found in a row with a height ranging between 5 m - 15 m and a diameter of 3-7 m (Fig.25). The shape of the pillar reflects the influence of vertical fractures, rock resistance, and sea-level changes. The granite undergoes subsurface weathering causing the regolith abrased and leaves a pillar-shaped resistant granitoid mass.

Fig.24 Pillar granite morphology, located at north of Tungkusan

Fig.25 Pillar on the coast of Tg. Kelayang

4.8.2 The minor granitoid landform

The minor landscape of Tanjungpandan granite is a form of weathering starting from the base of the Regolith, because the part is exposed, and starts from the surface. Minor granite landscape variations in the study area include gutters and grooves, flare slope, boulders, and aplite embankments.

Gutter and channel/trenches (grooves) and flute. The landform of gutters or channels is found in the dome of Perawas, Tanjung Pendam and Kandis hills in syenogranite and monzogranite with 10-15 cm width, 4-5 cm depth and UV-shaped profile, blackish color, rough-very rough surface and hollow as traces of xenolith, develop on steep slopes. Morphology of gutters or trenches was formed by erosion that vertical slices the regolith until the weathering front exposed and erosion continued following the slope. On steep slopes, it forms a straight gutter forming flute shaped (Fig.26), while on a gentle slope it bends following cracks.

Fig.26 Grooves (a & b) in Kandis hills and flute (c) in Tanjung Pendam

Flared slopes. Flared slopes are vertical, concave and wavy arches around the base of the hill, higher slopes and in cleft. Formed in stable tectonic conditions influenced by changes in climate variations. Flares are formed in 2 stages, namely: subsurface weathering that destroys rock walls. In the dry season, the surface of humid rocks causes weathering and erosion inward laterally and in the next stage peeling regolith forms a curved and concave weathering front (Fig.27). Flare slope can be shaped holes ellipsoid as shown in Fig.28.

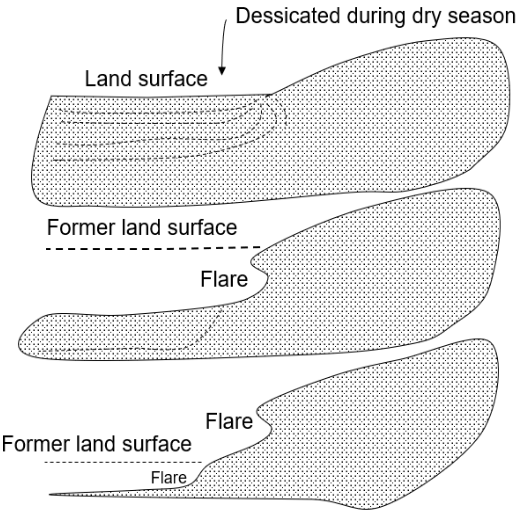

Fig.27 The mechanism of formation of flare according to Twidale, 1976 in [3]

Fig.28 Flare on land

Granite Landform called "Gerude bird headstone" at Tanjung.Kelayang offshore (Fig.29) is formed from a combination of sheet and vertical fractures. The bird's head and bottom are granite massifs with a wide space compared to the surroundings. The mechanism of forming "Gerude bird headstone" is similar to "balancing rock" in Perawas as a differential weathering product below the surface, the difference is "Gerude bird headstone" is offshore with stronger abrasion (Fig.30). Minor of gutters, trenches, and landscape range flare slope that occur due to changes in summer-rain.

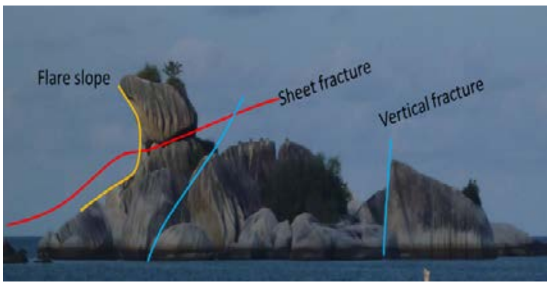

Fig.29 The "Gerude bird head rock" landscape at Tanjung Kelayang offshore

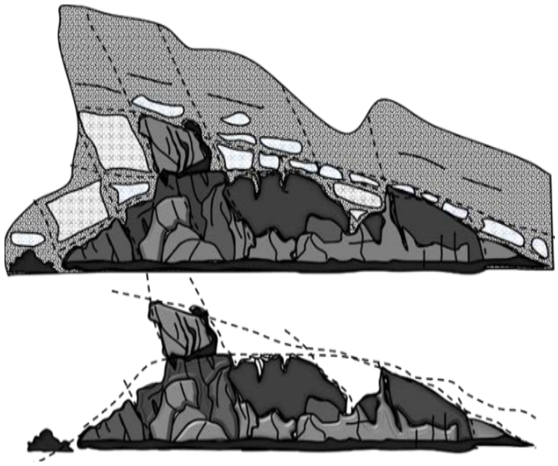

Fig.30 The evolution of the formation of Gerude bird head rock.

Aplite embankment. Aplite embankment with 10 cm width forming a protrusion on the surface of the monzogranite (Fig.31). The feature is found in Perawas Dome, a central part of Tanjungpandan granitoid.

Fig.31 Aplite embankment at Perawas Dome, central part of Tanjungpandan granitoid

4.9 Classification of Tanjungpandan Granitoid Landscape

Based on the size, shape, and mechanism, the Tanjungpandan granite is divided into a major granite landscape (Table 3) and a minor granite landscape (Table 4). The major landscape is formed due to differences in characteristics, granite resistance and the influence of large-scale fractures. While the minor granite landscape is caused by differences in mineral composition, texture, and chemical granite, micro-fractures that interact with climate change which results in chemical, biological, and physical selective weathering and erosion.

5. CONCLUSION

Based on [14] classification, the landscape of Tanjungpandan granitoid can be classified into major granite landscapes consisting of inselberg, dome, pillar, etch, castle koppies and nubbin, and minor granite range consisting of boulders, flare slope, grooves, valleys, and aplite embankments. The interaction of Tanjungpandan granitoid characteristics and fractures with weathering-erosion-transportation processes are influenced by climate change and sea-level fluctuations. The most dominant factor influencing the landscape of Tanjungpandan granitoid is the presence of vertical fractures and partial sheet fractures resulted in differential weathering below the surface. There is no significant effect on the granite characteristics.

Compared to the landscape of granite in other regions, the landscape Tanjung pandan granitoid is very unique due to the influence of sea-level changes and tectonic-magmatic of island arc which differ from continental granite [6].

6. ACKNOWLEDGMENTS

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Table 3 Classification of Tanjungpandan major granitoid landforms

Form	Dominant factor	Landscape	Location
Exfoliation, vertical and sheet fracture, subsurface weathering and erosion	Regional fracture, vertical fracture domination	Inselberg	Southern portion of study area
	Vertical fracture	Bornhardts	Perawas, Kandis-Tungkusan
	Sheet fracture	Nubbin	Perawas, Tungkusan
	Vertical fracture	Castle koppies	Tanjung Tinggi
	Vertical fracture	Etch	Perawas
	Vertical fracture	Pillar	Tanjung Kelayang, Kandis-Tungkusan

Table 4 Clasification of minor landscape of Tanjungpandan Granitoid

Form	Process	Convergence	Divergence	Location
Weathering	Weathering front	Gutters and grooves, boulders	Pitting, Flared slopes	Perawas, Tungkusan-Kandis, Tanjung. Pendam, Tanjung Tinggi
	The part is exposed		Plinths	Perawas
	Start on the surface	Gutters and grooves, Boulders		Perawas, Tanjung Pendam, Tanjung Tinggi, Tanjung Kelayang

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