Speleogenetic process of Suaran Block, karst of Sangkulirang–Mangkalihat, East Kalimantan

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Abstract. Karst of Sangkulirang Mangkalihat is one of the greatest karst areas in Indonesia and has hundreds of caves. Some of those caves are located at Suaran Block, one of the main karst block at this karst. This paper aims to study the speleogenesis process, as the fundamental process on karst landscape and cave development in that area. Speleogenetic process can be examined from the shape of the cave passage using uniformitarianism approach. That principle creates speleomorphology as the study of cave passage form and the factors that affect it. The examination of the cave passages uses cave maps to see the form and direction of them. As the result, caves at Suaran Block are formed mainly driven by geological structures such as fault – fissures and bedding plane which is indicated by linear form of the cave passage and water flow which shows sinusoidal form of the cave passage. Some caves are shaped by the combination of geological structure and water flows make them have mixed-induced speleogenesis.

1 Introduction

Sangkulirang-Mangkalihat Karst is located at Mangkalihat Peninsula, eastern part of Kalimantan Island. People and residents in the surrounding area of this karst have used it for generation to generation as dwelling location, for its swallow nest, and water resource where this karst provides water for most of the great river at Mangkalihat Peninsula such as Bengalon River, Kelay River, and Sangkulirang River. This karst is divided into several blocks and extended from coastal area into middle of central East Kalimantan encompasses total area of 362.706,11 acres according to Governor Regulation Number 67 Year 2012 About Protection and Management of Sangkulirang – Mangkalihat Karst Ecosystem in Berau and Kutai Timur Regency. Several notably blocks are Suaran, Merabu, Batu Kulat and Batu Tondayan, Batu Gergaji, Batu Nyere, Biatan, Batuputih, Tutunambo, Manubar, and Tabalar blocks. Each block exhibits particular endokarst and exokarst characteristics.

Previous expedition had revealed and studied endokarst characteristics of Merabu, Tondoyan, Tutunambo, Nyere, and Gergaji [1-6]. From those exploration, it is known that Sangkulirang – Mangkalihat karst has outstanding endokarst features. Hundreds of caves with various sizes and characteristics are scattered in this karst [7] and contains not only geological value but also the biodiversity [8, 9] and the archaeological [10] value. Nevertheless, most part of Sangkulirang – Mangkalihat remains unexplored yet.

This paper aims to elaborate the endokarst features of caves at Suaran Block in northern part of Sangkulirang – Mangkalihat karst where several caves had been explored on 2016 Expedition. The objectives of the expedition itself was to discover speleo-morphological aspects and parameters which will be used in describing the speleogenesis as the fundamental process of karst land forming. In terms of karst management, the process and dynamics of karst area must be protected. Understanding the whole process will help formulating strategy in protect and manage Sangkulirang – Mangkalihat Karst, particularly at Suaran Block let alone to establish this area as UNESCO Global Geopark [11] which is currently proposed.

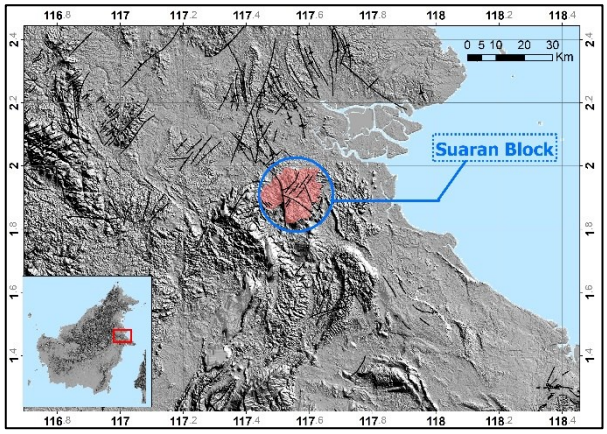

Fig. 1. Location of Suaran Block

2 Method

This research uses quantitative method to describe the caves at Suaran Block. Cave descriptions are based on cave passage's dimension and obtained by measurement of length, inclination, and direction of the passage. At each station, the Left, Right, Up, and Down (LRUDs) are measured to attain detail size of the passage. All those processes are known as Cave Mapping [12] and always applied to analyse the fundamental characteristics of the cave using speleo-morphological approach [13] and can

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be used to trace the speleogenesis process [14-17]. In total, we use 7 morphometric measurements (length between station, direction, inclination for the plan projection and Left, Right, Up, Down (LRUD for cross prejection) and for the quantitative parameters, this paper uses 4 parameters which are Cave Length (m) Cave Depth (m) Area of the cave passage (m^2). Cave Length and Cave Depth are then compared to yield precentage of inclination.

To analyze the data, this paper compares the passage's form with cave passage typology by plan section [18, 19]. Every typology has their own speleogenesis and the factors which affected it the most. The speleogenesis process is bounded only to epigenetic process which is driven by precipitation water [20] and composes of factors such as water flow and geological structures of joints and bedding plane. The typology can be seen at Figure 2 below.

	Control	Water Source
branchwork 	passage form	Doline
anastomotic pattern 	passage form	incoming
network 	fissure	seepage
spongework 	matrics porosity	Hypogenic
	fissure	Doline
	matrics porosity	Hypogenic

Fig. 2. Typology of Cave Planview [18]

Comparing cave passages form with the typology yields the main process of the speleogenesis. For more precise result, calculation of cave dimension are derived from the measurement of cave passage and done by using Compass software. Those calculations are used to determine morphometric properties. Because speleogenesis properties can not be separated from its geological or its surface settings, this paper also uses Geographic Information System to show the spatial distribution of cave entrance and the surface condition. To draw and visualize the Cave Maps, we use Survex software to produce the centre line and CorelDraw to finish the drawing. The drawings and results from calculation are required to yield information required to describe the speleogenesis process. These cave maps are the fundamental materials for the comparation since it visualizes the cave form in plan projection and cross prejection.

3 Results

3.1 Spatial Distribution of Cave at Suaran Block

Geologically, Suaran Block situated at Lembak Formation, Tabalar Formation dan Domaring Formation. Those three formations consist of Oligo-Miocene limestone [21]. Tectonic movements cause several massive geological structures such as fault and joint. From the geological maps, the major geological structure is directed to NW – SE with the minor fault is perpendicular toward it. This direction will later affect the cave passage orientation, particularly the structural-influenced passages.

Inside the Suaran Block, there are 12 caves that had been explored and mapped, scattered at the north and east side of Suaran Block. Those 12 caves can be seen on the Table 1 below and the spatial distribution of the caves can be seen at Figure 3.

Table 1. Caves at Suaran Block

No	Cave	Sector	Location	UTM 50N	
				X	Y
1	Kelencut Cave	Eastern	Selung Hills	569963	209982
2	Selung Air Cave			570221	210050
3	Kandar Cave		-	570854	210305
4	Melawang Atas Cave		Melawang Hills	570924	211936
5	Melawang Tengah Cave			570854	211903
6	Melawang Tengah1 Cave			570916	211957
7	Melawang Utama Cave			570933	211996
8	Bram Cave		Bram Hills	572674	210915
9	Kurandji Cave		Kurandji Hills	569227	211953
10	Mak Cave	Northern	-	562753	219514
11	Nunuk Cave		-	562065	220792
12	Burakat Cave		-	562077	220708

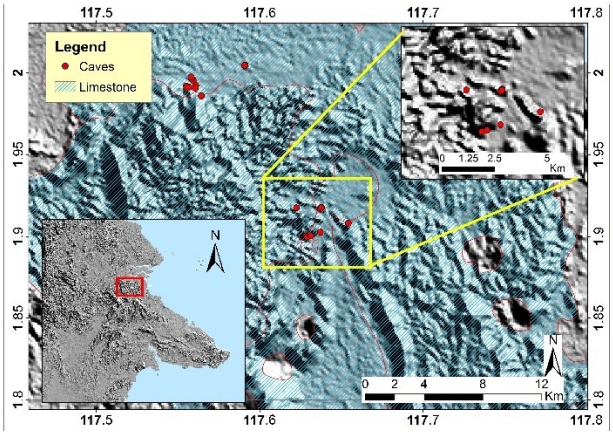

Fig. 3. Spatial Distribution of Caves at Suaran Block.

Limestone as the hostrock for karst is only presence at certain geological formation, in this case, Lembak, Tabalar, and Domaring Formation, the cave entrance distribution is concentrated only at those formations. East Suaran Block as the host of the caves consists of separated block and several isolated karst hills as can be seen at Figure 3 & Figure 4. Each hills or blocks at Eastern part of Suaran contains caves e.g. Brams Caves at Bram Hills, All Melawang Caves at Melawang Rocks and Selung Caves at Selung Hills. These separated blocks occurred due to the strong Fault process and is continued by erosion process from the river or water flow.

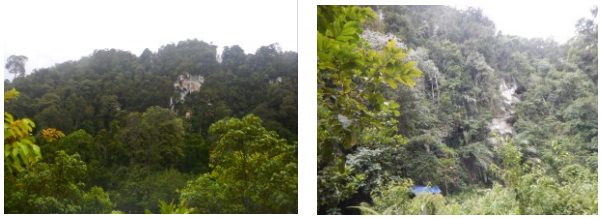

Fig. 4. Bram Hills and Melawang Hills

According to the geological and surface-morphological settings, the entrance distribution is grouped into each hills and cave entrances are located in isolated karst,. It means that every caves has their own system and not forming a joined system.

3.2 Fundamental Morphometry of Cave Suaran

Albeit all of the caves are located in a block, the length and cave passage's forms are varied from one to another as well as the depth of them. The length of the cave is the total single distance from the entrance to the end of the survey while cave depth is the difference between cave entrance and the lowest shot at cave passages. From the data we obtain, the longest cave is Melawang Utama Cave located at Melawang Rock and the deepest cave is the Kelencut Cave.

Each cave passage also has 3-dimensional perspective since it has the height and width. From the data of width and height, we could calculate the volume and surface are of every cave. The calculation of volume, surface area, cave passage area, and rock volume can be seen at Table 2.

Table 2. Fundamental Morphometry of Caves at Suaran Block

No	Cave	Cave Length (m)	Cave Depth (m)	Length /Depth (%)	Area of the cave passage (m^2)
1	Kelencut Cave	328.3	27.56	8%	3056
2	Selung Air Cave	313	12.50	4%	3219
3	Kandar Cave	59.61	4.24	7%	183
4	Melawang Atas Cave	62.68	3.48	6%	720
5	Melawang Tengah Cave	175.92	12.99	7%	1641
6	Melawang Tengah1 Cave	129.95	2.05	2%	1709
7	Melawang Utama Cave	435.63	18.87	4%	4418
8	Bram Cave	106.45	21.13	20%	397
9	Kurandji Cave	363.33	26.35	7%	2597
10	Mak Cave	36.2348	6.36	18%	352
11	Nunuk Cave	155.476	11.15	7%	6521
12	Burakat Cave	66.0762	8.93	14%	1334

Table 2 shows the morphometric parameters for caves in Sangkulirang – Mangkalihat blocks. Most of the caves are horizontal with each depth is not more than 30 meters meaning that the caves are horizontal. The precentages of inclination don't exceed 20% and indicates how the each caves passage are located in the same level of bedding plane and do not cut through it. The biggest precentage inclination is Bram Cave with 20% of inclination and the lowest is Melawang Tengah with only 2% of inclination.

Area of the cave passage represents how big the cave passage and the presence of chamber. Bigger numbers of area shows larger the cave passage is in terms of 3 dimensionals perspective. Melawang Tengah and Nunuk Cave are two of the biggest caves and it is related with the width and height of the cave passage and both cave also have many chambers that make the surface area bigger. The graph that shows this comparison can be seen at Figure 5.

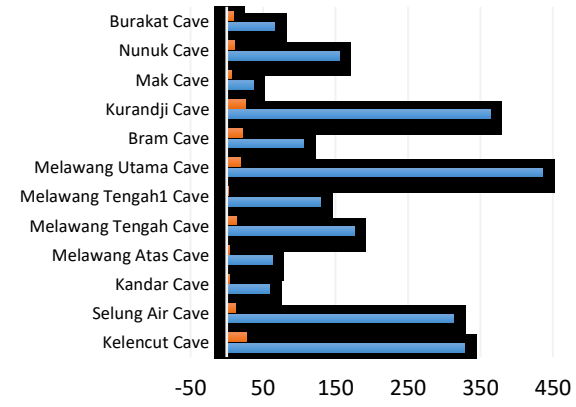

Fig. 5. Graphic of Length and Depth of Each Cave.

3.3 Morphology of Cave at Suaran Block

From the typology of cave passages, main factors that influence the speleogenesis can be divided into geological structure and water flow. The fundamental appearance that differs the geological structure and the water flow speleogenesis is the lineament of the cave passage. The geological structure speleogenesis tends to exhibit more lineament while the water flow speleogenesis shows sinusoidal pattern [19]. Lineaments are caused by tectonic movement or shifting which happens in a linear plane.

Thus, according to the speleogenetic process, caves at Suaran Block can be grouped into two main processes which are the structural-induced speleogenesis and the water flow/mixed-induced speleogenesis. The indication can be seen from the cave maps and the description below.

3.3.1 Structural Induced

Mak Cave has SE – NW linenanment and located at Tabalar Formation. The lineament is congruent with the major surface structure. The geological structure that plays major role is bedding plane and can be seen from the inclination and the fault which control the direction of the cave passage. The cave maps and the lineanment of cave passages can be seen at Figure 6.

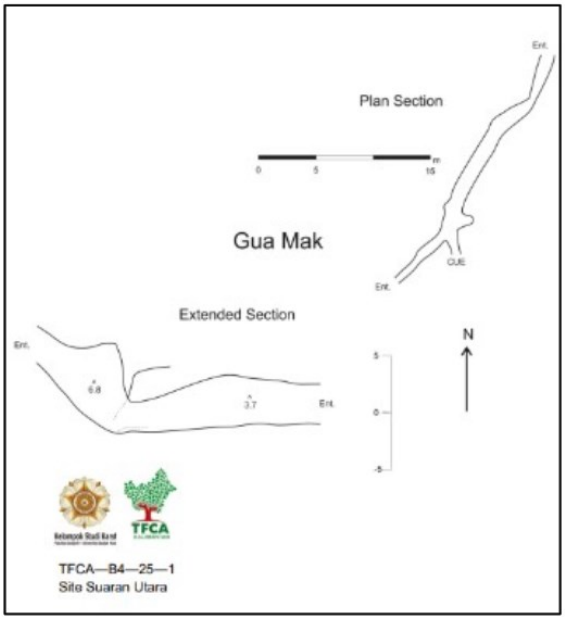

Fig. 6. Cave Maps of Mak Cave

Kelencut Cave performs major – minor geological structure in its cave passage indicated by a perpendicular direction of cave passage. From the entrance, there's a passage with N – S direction and then shift to W – E direction as can be seen at Figure 7. All the cave passages are linear and the structures that influences the speleogenesis the most are fault and bedding plane.

Selung Air (Water Selung) is basically a huge underground river located in the base of Selung Hill. Again, this cave shows a perpendicular pattern where from the passage from the entrace has N – S direction and continues by W – E passage as shown at Figure 8. The presence of incasion means that this cave has developed. Although there is a huge water flow, no sinusoidal pattern occurs due to the uniformity of the host rock facies.

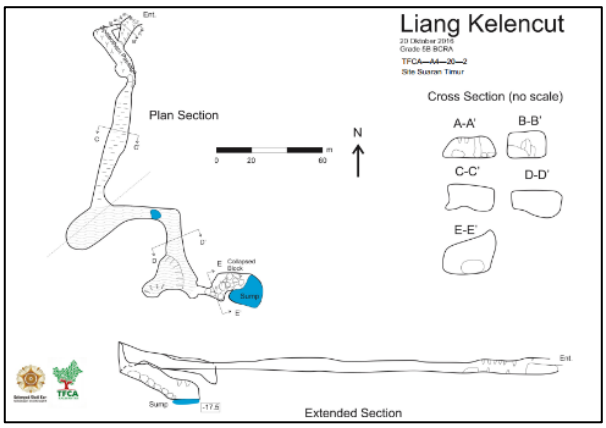

Fig. 7. Cave Maps of Kelencut Cave

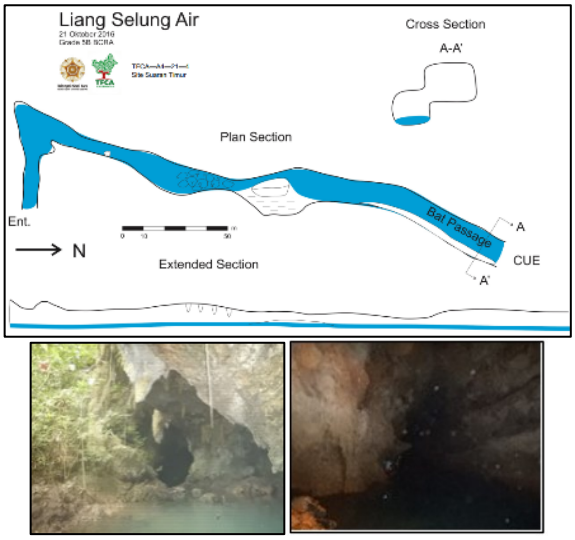

Fig. 8. Cave Maps of Selung Air Cave

Kurandji Cave is located at foot of Kurandji Hill. The speleogenesis process of this cave is strongly driven by geological structure of bedding plane and fault and it can be seen from the lineament of the most cave passage which has SE – NW direction. Several incasions in this cave are related with the late – stage of the speleogenesis process. Liang Kurandji maps can bee seen at Figure 9.

At Melawang Hill 3 of 4 caves, exclude Melawang Tengah, are mainly shaped by geological structure and expresses lineament whether complete linear or perpendicular lineament. Melawang Utama has the perpendicular lineament where the longest passage shows SE – NW direction. It is strongly influenced by bedding plane and fault. This pattern also happens at Melawang Atas where there is a perpendicular lineament form between the entrance and the continuous passage although the speleogenesis process at Melawang Atas appears to take later development due to the size of the passage and chamber of Melawang Atas. Melawang Tengah I forms a total lineament with SE – NW course. Size of the passage at Melawang Tengah I is much bigger and several incasion exists which indicates the later stage of speleogenesis. All 3 cave maps of Melawang Caves can be seen at Figure 10 to Figure 12.

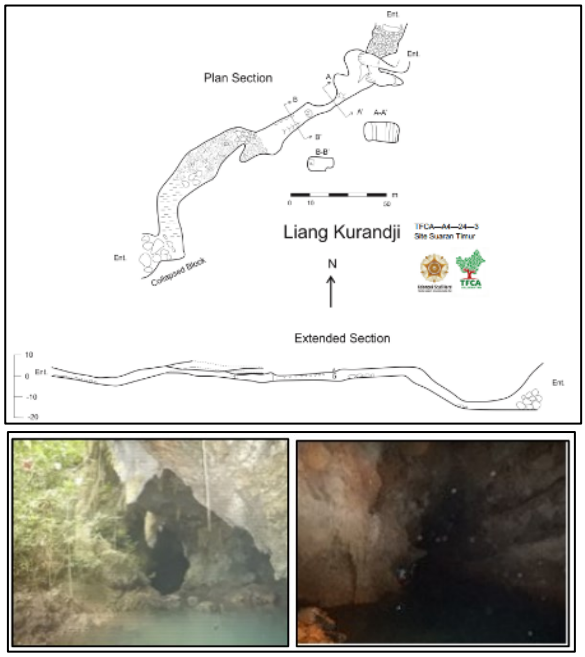

Fig. 9. Cave Maps of Kurandji Cave

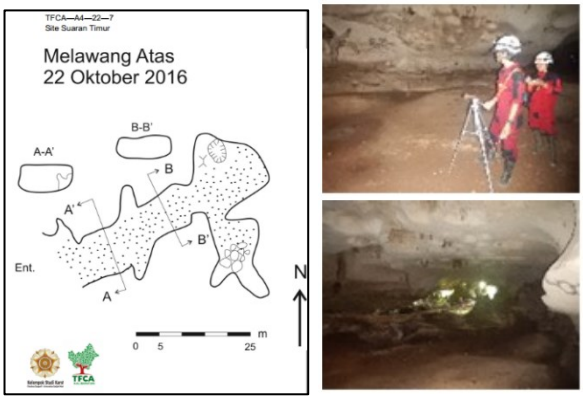

Fig. 10. Cave Maps of Melawang Atas

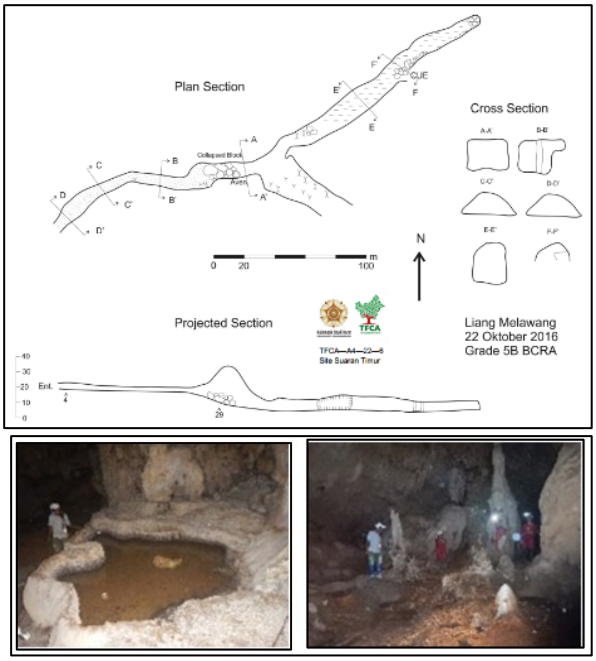

Fig. 11. Cave Maps of Melawang Tengah Cave

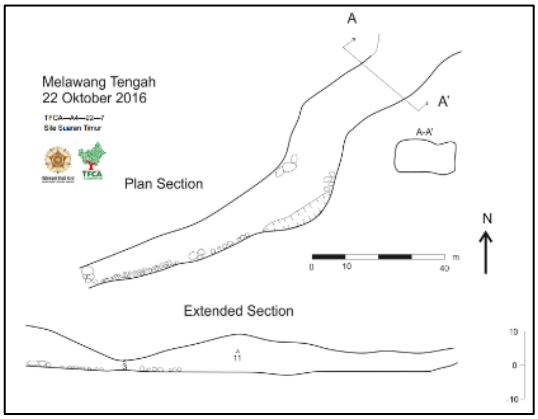

Fig. 12. Cave Maps of Melawang Tengah Cave

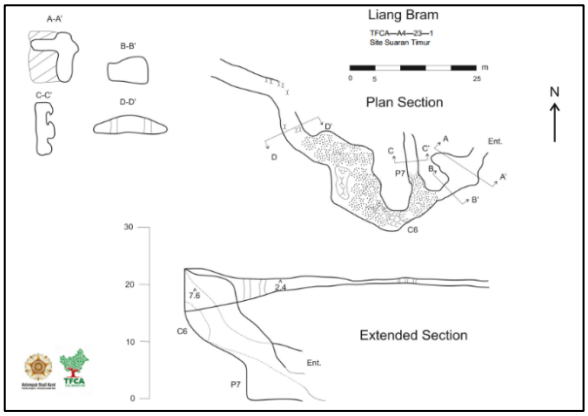

Fig. 13. Cave Maps of Bram Cave

The entrance of Nunuk Cave is located at foot hill and situated at Tabalar Formation. This cave has W – E direction and perpendicular pattern. The fault that controls this cave also has vertical dimension and can be seen from the height of the passage. In several part there were incasions. The cave maps of Nunuk Cave can be seen at Figure 14.

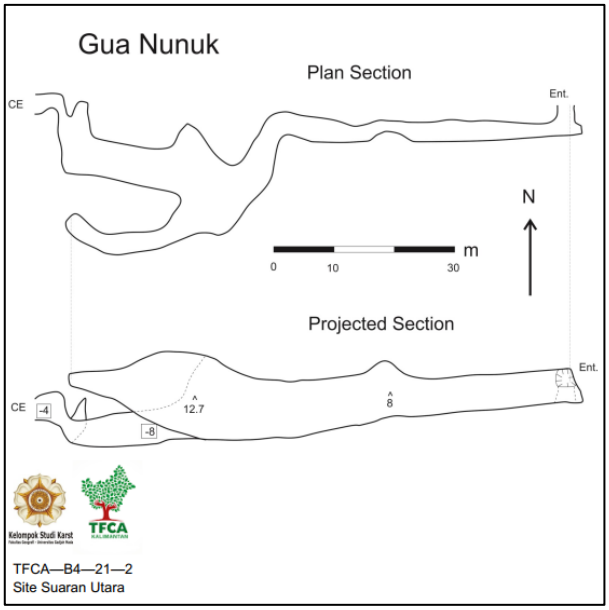

Fig. 14. Cave Maps of Nunuk Cave

3.3.2 Water Flow/Mixed Induced

Despite the small size and the cave passage is relatively short, Kandar Cave appears to be the clearest water flow speleogenesis induced. It has water inside and uniform cross section passage form of Gorge-form. The plan section shows bold sinusoidal pattern which is strongly related with water flow. Water flow influence also can be seen from the absence of cave ornament. The meander form of this cave can be seen at Figure 15.

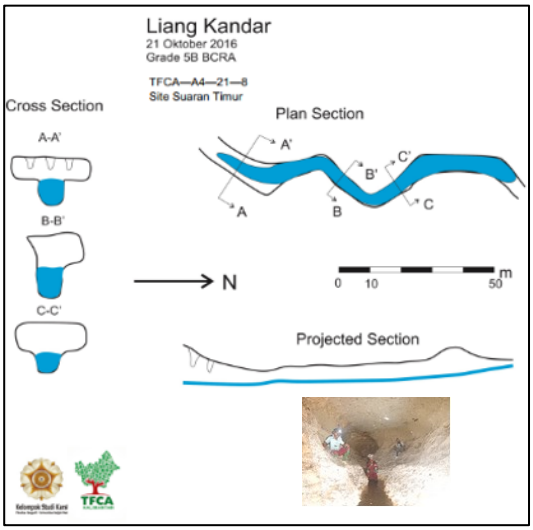

Fig. 15. Cave Maps of Kandar Cave

Melawang Tengah (Middle Melawang) is the only cave at Melawang Hill with mixed speleogenetic factor. In this cave, geological structure and water flow appear together, forming a linear and sinusoidal pattern. The geological structures that play major role is the bedding plane and fault which has NE – SW direction. No perpendicular structure exists in this cave as can be seen at Figure 16.

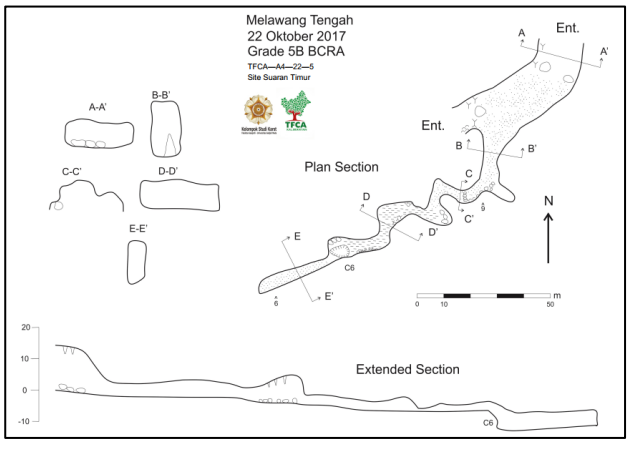

Fig. 16. Cave Maps of Melawang Tengah Cave

Burakat Cave is located at the mid hill and has multiple entrances. This cave is situated at Tabalar Formation. The water flow influence can be seen from the sinusoidal shape. Beside the water flow, geological structure also plays role in this cave and can be seen at several perpendicular cave passages at the entrances. There are also slope passages and related with the development at bedding plane. Cave maps of Burakat Cave can be seen at Figure 17.

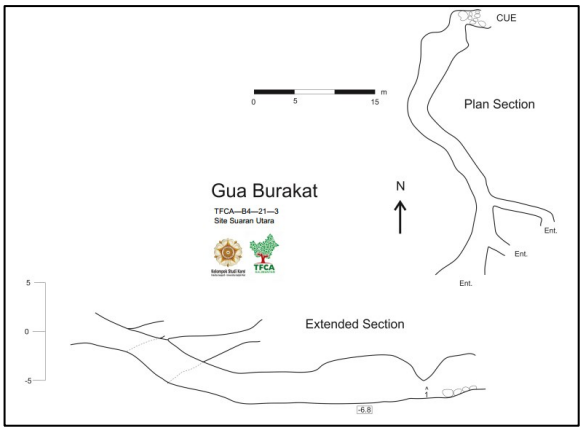

Fig. 17. Cave Maps of Burakat Cave

4 Discussions

Based on the morphology, there are two main factors that drive the speleogenetic process which are: geological structure and water recharge. Principle differences of those processes are linearity of cave passage. Structural induced forms more linear passage since the geological structures are always linear while the water flow would exhibit meander or winding. The structure acts as weak plane where water can infiltrate the limestone hence causes dissolution and emphasize the fissure into cave passage, it can be fissure, bedding plane, or both [18] while the water that charges the limestone could come from karst depression, diffuse flow, or hypogenetic.

Examination of cave passages at Suaran Block show all of the caves has the angular – curvelinier passage or network passage. It means that all of the speleogenetic process is epigenetic or the water recharge comes from precipitation or rainfall.

Regardless, it is likely to have more than one process in a cave that resulting different pattern. It can be clearly seen at Melawang Tengah Cave where it has both linear pattern as the result of geological structure and sinusoid pattern as the result of water flow. In addition, each pattern has different size as the indication of both process from geological structure and the water flow control.

The subtlest single processed pattern happens at Kandar Cave. This cave has uniformity of cave passage shape from the top to bottom. Almost all of the cross section of the passage appears to have gorge-form shape. This shape occurs because of the fast lifting on the host rock, causing a drop on water level. Kandar Cave also shows scallops pattern on its wall as the sign of fast water flow.

Another unique pattern is the perpendicular form where most of the cave appears to have it. Melawang Utama, Kelencut, and Selung Air exhibit this pattern and strongly related with the presence of regional geological structure and proves that every process that happens inside the cave is related with the setting the caves are situated [22]. The geological structures can be seen at the Figure 18 and the Rose Diagram of faults direction can be seen at Figure 19.

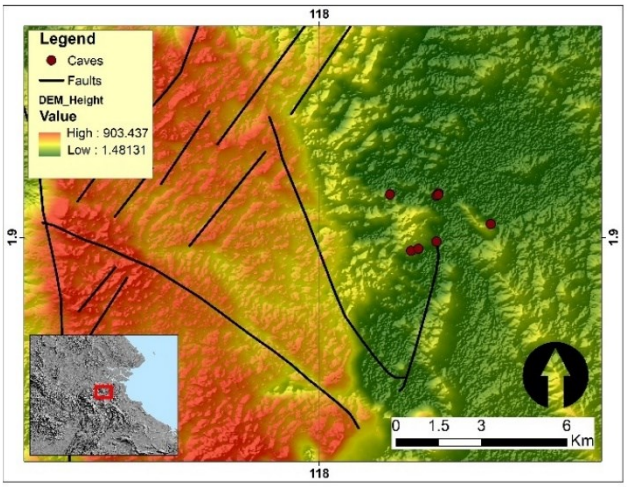

Fig. 18. Faults at Suaran Block *(sources: 1:250.000 Geological Map)*

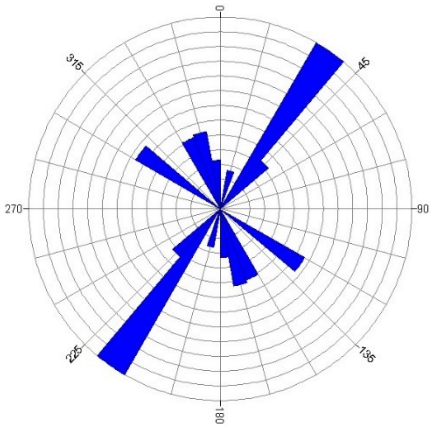

Fig. 19. Rose Diagram of Faults at Suaran Block

Major structure at Suaran Block has NE – SW direction. Compression from that direction rips off the limestone making a fissure perpendicular to the major structure which has NW – SE direction. This fissure later becomes the cave passage because of the enlargement by dissolution of water.

The rose diagram at Figure 20 shows how local structure affects the direction of the cave. Caves at Melawang Hill (Melawang Atas, Melwang Tengah, Melawang Tengah I, and Melawang Utama Cave) tend to have NE – SW course. Meanwhile, caves at Selung Hill (Kelencut and Selung Air) have similar direction of N – S direction. The direction also can be compared with the rose diagram of faults direction. Caves that induced by geological structure such as Melawang Hill's caves appear to have similar Rose Diagram with the faults direction mainly the minor structure. Mak and Kurandji Cave also resemble identical direction with the main fault direction.

Water also has fundamental role in speleogenetic process. Palmer [18] divided the water flow into three categories of karst depression, diffuse, and hypogenetic. All of caves at Suaran Block are included into karst depression or diffuse because it has branchwork or network pattern which heavily influenced by them.

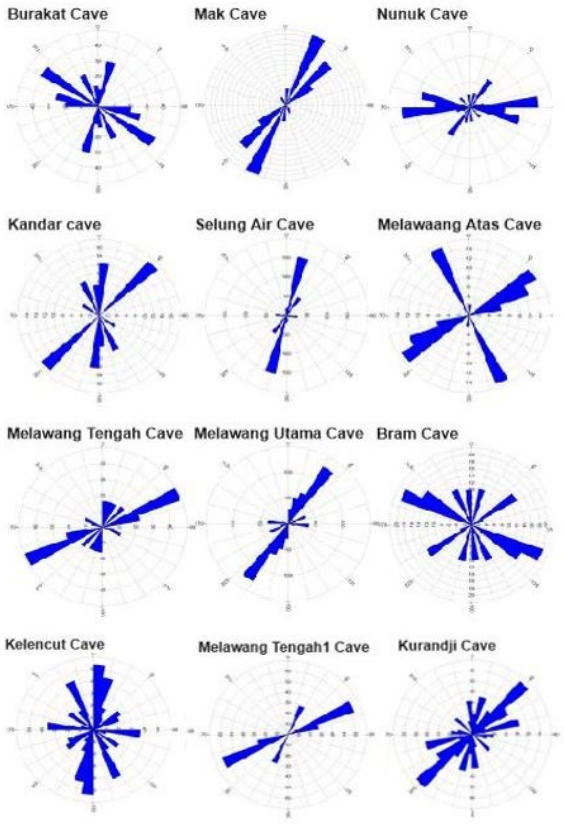

Fig. 20. Rose Diagram of Caves at Suaran Block

Further, for the karst depression, the water flow could come from sinkhole which has more steady flow of sinking stream which has high fluctuation of water flow. Steady water flow will cause a more sinusoid pattern because the water flows steadily and may have time to search for a weaker plane or higher porosity. Meanwhile, at sinking stream, water flow is more rapid causing water follows the lineament of the structure accordingly. For the comparison, Kandar Cave which has sinusoid pattern is located at sinkhole and steadily flooded by water while Kelencut Cave is located at sinking stream, causing it has bolder lineament.

The presence of incasion has to be acknowledged. Incasions or collapsed part of the cave significantly shapes the cave passage and alters the previous form. Incasions are also sign of the later development of a cave.

In contrast with the Karst of Maros and Gunung Sewu as two of the most notably karst areas, Suaran Block of Sangkulirang – Mangkalihat Karst has more separated block/isolated hills and cave system is developed in that isolated hills. It could be seen at Melawang Hills and Bram Hills where each hill has its own cavity system respectively Melawang Caves and Bram Cave. Gunung Sewu doesn't have this kind of separated cave system since it has massive and united limestone block. Another factor that influences this is the karst development and maturity. Sangkulirang – Mangkalihat Karst, particularly at Suaran Block was lifted sooner than Gunung Sewu Karst and massive rainfall induced heavy errosion which eventually cut off the massive block of Sangkulirang – Mangkalihat block and separate the karst.

5 Conclusion

Based on the morphology, caves at Suaran Block can be divided into branchwork – curvelinier and network pattern. The direction of cave passage follows the course of regional and local geological structure. Those patterns and directions are related to the role of geological structure of fissure or joint and bedding plan and water flow from karst depression.

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