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Role of Geological and Structural Controls in the Development of Karst Topography: A Study of Green Cave, Kanger Valley, Bastar Region, Chhattisgarh

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Abstract
The Green Cave is a prominent karst structure that was produced within a structurally deformed carbonate landscape. It is situated in the Kanger Valley region of Bastar, Chhattisgarh, close to the Kanger Dhara Waterfall and Kotumsar Cave. The impact of geological features, including folds, faults, joints, striations, and Stylolites, on the formation and evolution of the cave system is investigated in this study. To comprehend the connection between tectonic deformation and karstification processes, extensive field research was conducted, including structural mapping and geomorphological observations. This specific cave's entrance is oriented in such a way that sunlight can enter the cave, because of this event, the cave has adapted to the particular natural conditions required to thrive in a cave, allowing algae, fungi, and several small plants to flourish there, giving it the appearance and name "Green Cave."

Keyword: *Green Cave, Stylolites, Folds, Faults, Joints, Striations, Speleogenesis, Structural Deformation.*

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I. Introduction

One of the most unique geomorphic systems are karst landscapes, which are mostly created by the dissolution of soluble rocks like gypsum, dolomite, and limestone. Features like caves, sinkholes, subterranean drainage systems, and solution voids define these terrains. The development of karst systems is controlled not only by lithology and climate but also significantly influenced by geological structures, including folds, faults, joints, and other discontinuities that regulate groundwater movement and dissolution processes have a major impact on the development of karst systems.

The Kanger Valley region of Chhattisgarh, particularly the area surrounding Kanger Dhara Waterfall, represents an important karst terrain developed within carbonate rock sequences. Among its significant characteristics, Green Cave is a structurally controlled cave system that offers important insights into the relationship between karstification and tectonic deformation. Folding, faulting, jointing, striations, and stylolites are examples of the region's strong structural activity, suggesting several stages of deformation that have altered the rock fabric and affected secondary porosity. (Zabidi et al., 2016).

Despite the geological importance of the Kanger Valley caves, detailed studies focusing on the structural control of karst development in Green Cave and its surrounding area remain limited. Thus, the purpose of this study is to look into the connection between the region's karst processes and structural components. Analysis of how folds, faults, joints, striations, and stylolites influence speleogenesis, groundwater flow, and cave morphology is given particular attention. This research contributes to a broader understanding of karst evolution in tectonically active and structurally complex terrains and provides valuable insights for geological mapping, groundwater studies, and conservation of fragile cave ecosystems. (Brinkmann, & Garren, 2011).

II. Study area

Green Cave is situated in Bastar, Chhattisgarh's Kanger Valley National Park. The cave is located at N18°52'7.2", E081°55'57.9" and is 558 meters above sea level. This cave has a total length of 93 meters. Green Cave is located 1140 meters southeast of the Kanger Dhara waterfall, The distance between Kotumsar Cave and Green Cave is 200m and situated at south of the Kotumsar cave. Green Cave belongs to Kanger formation of Indravati basin which cover toposheet no 65F/13.

III. Methodology

The methodology of this study is based on entire field investigation and structural-geomorphological examination of the Green Cave region in the Kanger Valley, close to Kanger Dhara Waterfall. Lithology, cave morphology, and surface karst features were mapped using detailed geological traverses, and the orientation (strike and dip), frequency, and spatial distribution of structural elements like folds, faults, joints, striations, and stylolites were systematically measured using a geological compass. To comprehend their relationship to structural discontinuities, cave passageways, chambers, and solution features were recorded. The shape and spatial distribution of subterranean passageways in the Green Cave system were recorded through the use of systematic field survey techniques. Passage (trend), width, height, and length were recorded, together with the orientation of structural elements such joints and faults that regulate passage development, using a compass, measuring tape, and a visual estimation. From the cave entrance to the internal chambers, survey stations were set up at regular intervals, and plan view and cross-sectional profile sketches were created. In order to examine the predominant orientation patterns of discontinuities such joints, faults, and bedding planes and passageways, a rose diagram of the structural features in the Green Cave region was created. A geological compass was used to get field measurements of strike directions while the research area was methodically mapped. The information gathered was then combined to create a detailed cave map, which was utilized to examine the connections between karst development, structural discontinuities, and passage direction within the cave system. A conceptual model explaining the function of tectonic deformation in directing groundwater movement and speleogenesis within the Green Cave system was developed as a result of the analysis of the gathered data to identify connections between structural controls and karst development.

IV. Geological Information About Green Cave:

The Green Cave's entrance is huge, measuring around 8 meters in height and 4 meters in width, which is unusual in the Kanger Valley Region. The first corridor is 10.66 meters long and resembles a natural ramp. It is gently sloped and strikes 140° and 320° directions. This corridor forms two chambers that trend in the directions of 120°–300° and 175°–355°, respectively, and a third long, narrow gallery that trends in the directions of 180°–360°. It eventually grows and approaches 9.52 meters in width. From one end to the other, the first spectacular corridor slopes gradually to a depth of 9.01 meters. A very prominent green speleothem with a radius of 220 cm is developing at a significant joint that trends from 55° to 235° at the end of this route. This speleothem's sun-facing section contains enough water and is exposed to sunlight; small plants grow there and seem green. The green speleothems are contrasted with two more white speleothems of varying sizes. This section of the cave contains a cave pillar that is 5.48 meters high, a little white stalactite that is 3.3 meters long, and another comparatively large stalactite that is 5.39 meters long. The first chamber, which trends from 120° to 300°, is roughly 9.32 meters long and 5.05 meters wide. This chamber displays well-developed speleothems. The second chamber is 15.7 meters long and 3.7 meters wide, with a trend of 175°-355°. Three prominent joint sets have been noted in this chamber The first joint sets are oriented between 175° and 355° parallel to the chamber. The third joint set trends from 70° to 250°, while the second joint set trends from 130° to 310°. At the chamber's blind end, prominent speleothems form. (Gupta, 2024).

This chamber is approximately 11.82 meters high and 3.7 meters wide. In this room, a distinctive roof solution dome is being built. A connecting passageway that connects the second chamber to a long linear gallery is 8.95 meters long and has an entrance width of 6.6 meters. As it gets closer to the next connected gallery, it tapers or narrows down to a width of 1.6 meters and a height of 0.78 meters, making it extremely difficult to move. (Kambesis, 2007).

Plate No. 1 - Green Cave (Green coloured stalactite)

The trend of this route is between 70° and 250°. There are multiple parallel inclined joints in this corridor. These parallel inclined joints have an inclination of 30°, a dip direction of 115°, and a trend of 25° to 205 The longest gallery that is connected to the aforementioned passageway turns 180 degrees and 360 degrees. This gallery is 32.08 meters long overall, with varying width and height. The height ranges from 1.01 to 4.2 meters, while the width ranges from 2.5 to 5.8 meters. There are four cave pillars across this entire gallery. The first cave pillar is 1.9 meters high and has a circumference of 3.4 meters. The second cave pillar is 1.04 meters high and has a radius of 4.2 meters. The circumference of the third cave pillar is 1.15 meters. This section is significant because of the surrounding calcareous soil and a 4-meter-deep hole. Four sets of joints running 180°-360°, 80°-260°, 55°-235°, and 150°-330° are present in this section. This gallery includes a linear chain of stalactites and a joint system that trends 180° to 360°. This gallery now turns 160° to 340°; it is 8.2 meters wide and has pillar 4.

Table – 1 Structural Data of Green cave (after Gupta, 2024)

NAME OF CAVE	LOCATION-GALLERIES	JOINTS	TRENDS OF JOINTS	TRENDS OF GALLERIES AND CHAMBERS OF CAVE
GREEN CAVE	First passageway	1. Major joint. Green stalactite associated with this joint	55°-235°	150°-320°
	Chamber 2	1. Joint sets are parallel to the chamber	175°-355°	175°-355°
		2	70°-250°	
		3	130°-310°	
	Second passage way	1.Severeal parallel inclined joints	Joints trends - 20°-200	70°-250°
			Dip direction- 110°	
			Dip amount - 30°	
	Longest interconnected gallery	1. Joint sets are parallel to the chamber and that has a linear chain of stalactites.	180°-360°	180°-360°,
		2nd Joints sets	110°-290°	
		3rd Joints sets	80°-260°,	
		4th Joints sets	55°-235°	
		5th Joints sets	150°-330°	
	Another linear gallery	1. Joints sets	115°-295°	20°-200°
		2. Joints sets	20°-200°	
	Last chamber	1. Major joint. stalactite associated with this joint	145°-325°	
		2. Joints sets	45°-225°	

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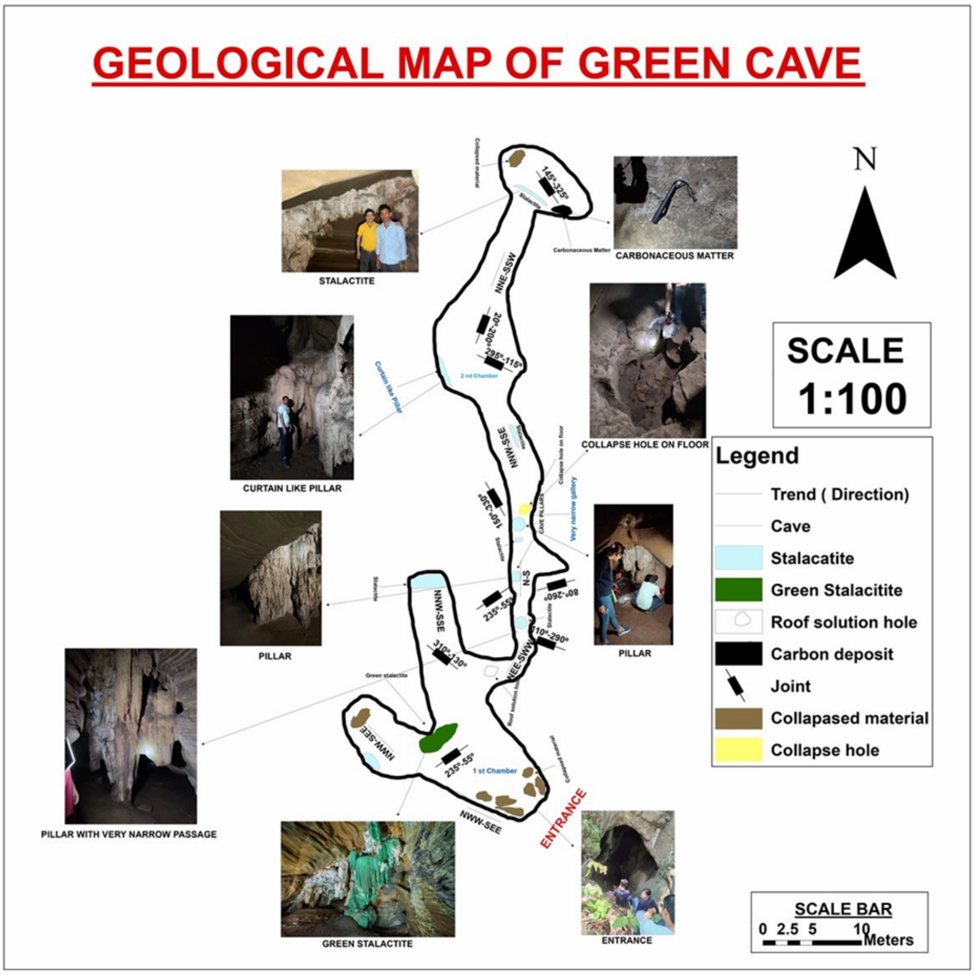
In reality, this pillar is a ridge-like structure that is attached to the gallery wall it is 5.7 meters long and 1.3 meters high, respectively. This gallery is 13 meters long and connected to another linear gallery that trends in 25°–205° directions. Two sets of joints, running 115°-295° and 25°-205, respectively, occupy the gallery's entry. This gallery ranges in width from 7.36 meters to 2.1 meters. This gallery is connected to a chamber that is 6.2 meters long and 4.6 meters wide. This chamber also exhibits a carbonaceous thin lamination and joint that trends from 45° to 225°. Stalactites are also formed along these joints. (Gupta, 2024).

V. Morphology and Patterns of Caves

The shape, structure, development, and spatial organization of caves are referred to as cave morphology and pattern. It is strongly related to geology, hydrology, and climate and is mostly researched in the subject of speleology. The actual arrangement and interconnection of passages inside a cave system, particularly as it relates to speleology, is referred to as the cave pattern. (Biswas, 2022). It explains how water flow dynamics and geological structure determine how underground channels are arranged. Branch work patterns, which connect smaller passageways to larger trunk routes like a tree, Network or Maze patterns, which are made up of interconnected loops, angular patterns, which are governed by rock joints and fractures, Sponge work patterns, which have irregular, porous voids, and anastomotic patterns, which form smoothly interconnected channels, are examples of common cave patterns. These patterns, which are mostly seen in soluble rocks like limestone, are influenced by a number of variables, including the kind of rock, structural controls, groundwater circulation, and the evolutionary phases of caves. (Palmer, 1991, Paryani, & Haryono, 2022).

Changes in base level, recharge types, and geologic structure are the main factors influencing cave patterns. Anastomotic caverns, whose curved tube junctions resembled a web of interconnected rivers. Closed loops are common. (Dar, 2022).



Map no. 1. Geological map of Green Cave (after Gupta, 2024)

Single passage Caves it is thought that certain caves, which have only one passage, are rudimentary (underdeveloped and immature) forms of the other cave formations. (Palmer, 1991). Caves are large, irregular rooms with galleries extending from the main development zone. Maze Type Cave the network and anastomotic pattern of the caves combine to create a structure like a maze with complete loops where pores or cracks meet and grow at the same time. (Dar, 2022). The research area's caves' morphological characteristics, such as their size, dimensions, and conduit cross-section, indicate that Green Cave is single passage caves and exhibit rudimentary, immature versions of the other caves. (Gupta, 2024).

VI. Structural Information About Study Area

Geological structures like bedding planes, joints, fractures, faults and folds are of utmost significance because they host and regulate nearly all of the subterranean solution conduit networks which distinguish the karst system apart from all others. (Ford, & Williams, 2007, Tirla, & Vijulie, 2013).).

Kanger valley region is a part of Indravati Basin. The Indravati group of rocks are essentially horizontally bedded or low dips between 5 to 20 degrees, but in Kanger valley National Park and adjoining areas the rocks are highly deformed. This deformation is due to the regional and local structural events. The Bastar craton and Indravati basin is surrounded by two mobile belts viz. the Eastern Ghat mobile belt on the East and the Satpura mobile belt on the North West, where as the Mahanadi and Godavari rift marks the North East and south western boundary of the Bastar craton (Yellappa et al., 2011). Additionally, these rocks are disturbed primarily by the most pronounced Sirisguda fault; roughly trending East -West, other noteworthy faults of the Indravati Basin are Tirathgarh, Keam Karka, Kanger Dhara. Apart from the above structural events other local structural events played significant role in deforming the rocks of the basin which ultimately leads origin and evolution of the Karst topography in this area. Several intrusive events took place in and around the Kanger valley region. The adjoining Darbha and Tongpal region witnessed events of acidic magmatism where as Tokapal and Tirathgarh area witnessed basic intrusive events. Some quartzolitic intrusive events also affected. Intrusive events disturbed the rocks as a consequence of that several folds and joints were formed. (Babu, 1994, Sloss, and Speed, 1974).

Presence of Tirathgarh, Keam, Karka faults elevated the south and South Western region of the basin. Study area belongs to the down throw blocks of the above-mentioned faults. All the faults are of this region are normal faults. The study area is in the North East portion of the faulted terrain. The Sirisguda fault is a type of pivotal fault, here sandstone forms topographic high and occupies the North Western portion with respect of research area. All the events are ultimately formed joints, fractures, folds and expose the Kanger limestone and promoted Karst development in this region. Crack expansion leads to the development of karst, as water erosion on rock mass typically starts with joint fissures. Accordingly, the direction and amount of karst formation are often determined by the degree of fissure development and the direction of its extension. (Ramakrishnan, 1987, Gupta al el., 2022).

Plate No. 2 - Picture Shows Folding in shale near Kanger Dhara

VII. Kanger Dhara Area

The small but stunning Kanger Dhara waterfall is situated close to Kotumsar village in the Bastar district of Chhattisgarh's Kanger Valley National Park. This waterfall is located 475 meters above mean sea level and approximately 38 kilometers from the Jagdalpur divisional headquarters of Bastar Division. Its coordinates are N18°52'26.94", E81°55'24.9". The Indravati Basin's Cherakur shale and sandstone comprise the Kanger Dhara waterfall. A curious person can see picture-perfect folds, joints, flaws, slippery sides, stylolites, etc. in addition to this magnificent waterfall. The formation of different structural characteristics in the Kanger Dhara area can be explained by the presence of a quartzolitic intrusive body (quartz reef). Because of the Kanger fault, the Cherakur shale and sandstone are visible on the surface. Kanger Dhara Waterfall is adjacent to Kotumsar Cave, Dandak Cave, Green Cave, and New Cave. Green Cave is 1319 meters away from Kanger Dhara at an angle of 122 degrees. Gupta et al., 2021)

VIII. Structural Information of Kanger Dhara Area

Kanger Dhara is a perennial river that makes a small but beautiful waterfall. This waterfall is created by the Kanger Dhara fault, which is running ESE-WSW. There are significant structural imprints throughout. The upliftment, faulting, jointing, and folding in this particular location may be caused by a single local quartzolitic intrusive body. Cherakur shale and sandstone elements in the Kanger Dhara region are severely deformed, whereas the Indravati group of rocks is typically undisturbed and gently sloping. Some unique features of this region are revealed via thorough geological mapping: Polyphase deformation may have occurred in the area. This region develops a variety of folds, including Antiformal, Synformal, Plunging, Similar folds, Domes, and Basins. There is some minor reverse faulting, which is unusual for the Indravati Basin. (Gautam et al., 2014). The association between major and minor joints and the main deformational events has been recognized. Faulting, jointing, and folding occurred as a result of a period of violent intrusive activity in the Kanger Dhara area. The influence of violent events in and around the Kanger Valley Region in the formation and evolution of the region's karst topography. Near the Kanger Dhara Waterfall, there was a violent intrusive incident. (Gupta, 2024). The Indravati Group of rocks in this region was invaded by a single quartz reef (Quartzolite) (GPS location: N 18°52'25.79, E 81°55.25.03, Altitude: 499m). The superincumbent rocks in this region were elevated, faulted, jointed, and folded by this intrusive event. Today's downstream section of the Kanger Dhara has been raised to a height of several meters by this intrusive event. It's possible that this raised area created an elevated ridge. Because of its excellent jointing and folding, this raised ridge was susceptible to weathering and erosion. This high terrain was progressively eroded and is now a valley. The Kanger limestone rock formation may have been exposed on the surface and well-jointed as a result of all these geological deformation processes. The existence of stylolite in this area also suggests that the rocks there are under a extensive of pressure. Numerous limestone caves were made possible by the area's streams and well-jointed, thick, exposed carbonate rocks. The common trends are identified by structural investigation of a number of folds and joints in the Kanger Dhara area: The first orientation is between 10° and 190°, the second is between 100° and 280°, the third is between 70° and 250°, fourth is between 55° and 235°. The region's dramatic and dynamic palaeogeographical events can be explained by the existence of intrusive bodies, stylolite, folds, joints, and faults. (Gupta et al. 2021).

Table No. 2 - Structural Data of Kanger Dhara Area (after Gupta, 2024)

S. No.	STRUCTURE	DIRECTION
1.	Joint	70°-250°
2.	Joint	55°-235°
3.	Joint	70°-250°
4.	Joint	55°-235°
5.	Joint	10°-190°
6.	Joint	55°-235°
7.	Joint	70°-250°
8.	Joint	100°-280°
9.	Joints Associated with Fold	70°-250°
10.	Joints Associated with Fold	10°-190°
11.	Joints Associated with Fold	5°-185°
12.	Joints Associated with Fold	110°-290°
13.	Joints Associated with Fold	100°-280°
14.	Joints Associated with Fold	130° - 310
15.	Joints Associated with Fold	70°-250°
16. Intrusive body	Joint	10°-190
	Joint	55°-235°

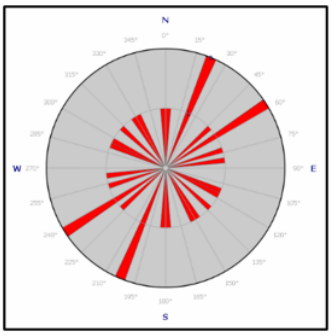


Fig. 1 Joint directions in the Green Cave

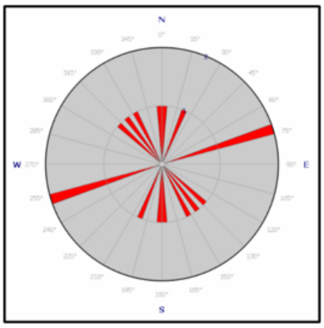


Fig. 2 Directions of Galleries Inside the Green Cave

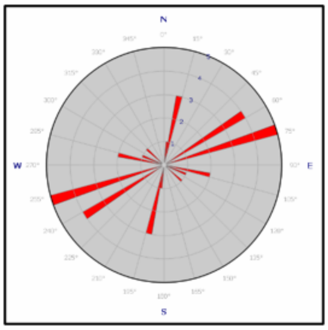


Fig. 3 Joint directions in the Kanger Dhara

Rose diagrams show most of the Joints (near and inside the cave) and galleries of all caves are following similar trends along the direction of NE-SW. In Green Cave most of the prominent joints are clustered approximately along NE-SW quadrants. Some galleries, joints, and speleothems follow the similar trends. One interesting observation is that some galleries do not follow any structural trends it means hydrodynamic action inside the cave also played vital role during the development of galleries and pathways inside the cave. The joint trends of green cave resemble with the joint trends of the Kotumsar, Dandak, New Cave and the Kanger Dhara waterfall area. Most common alignment of galleries of caves are 70°-250°, 10°-190°,100°-280° directions which coincides with the major joint's trends in nearly Kanger Dhara. (Gupta, 2024).

IX. Conclusion

It is evident from the geological and structural study of Green Cave in the Kanger Valley region close to Kanger Dhara Waterfall that structural discontinuities in the carbonate terrain have a significant influence on karst development. The majority of joints, both inside and outside the cave, show a dominating NE–SW trend, according to field observations, cave mapping, and rose diagram analysis. These structural orientations are generally followed by cave passageways and galleries, indicating that joints and fractures serve as the main conduits for speleogenesis and groundwater movement. The structural influence governing cave geometry is further supported by the clustering of significant joints in the NE–SW quadrants. However, some cave galleries do not precisely follow the predominant structural patterns, indicating that hydrodynamic processes have also had a major influence on the shape of the cave. Thus, the evolution of conduits and chambers within the cave system has been impacted by the interaction between structural controls and groundwater dynamics. Furthermore, Green Cave's joint orientation patterns strongly resemble those of neighboring cave systems like Kotumsar, Dandak, and New Cave, as well as the Kanger Dhara waterfall area, suggesting a structural regime that is stable throughout the region. Major joint trends throughout the research area closely match the most prevalent cave gallery alignments (70°–250°, 10°–190°, and 100°–280°). Discontinuities including joints, faults, folds, striations, and stylolites, according to field observations and structural research, are essential for directing groundwater movement and starting dissolution processes. It is confirmed that these features serve as speleogenesis paths by the alignment of cave passageways with dominant joint and fault orientations. Additionally, multiple phases of deformation have enhanced secondary porosity and permeability, facilitating the enlargement of fractures into well-developed cave systems. The study finds the conclusion that the origin, evolution, and shape of Green Cave are primarily controlled by tectonic features. These findings advance our knowledge of karst processes in structurally complicated terrain and offer important information for groundwater research, geological mapping, and the conservation of cave environments.

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