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Physical and Environmental Characteristics based Classification of the Caves of the Andaman Islands

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Study Area: Andaman & Nicobar Islands

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Abstract

The objective of the study was to classify the caves in the Andaman Islands, on the basis of their existence, rock layer type, cave size, cave openings (number, size, and shape) and the presence of light zones inside. All the 314 caves visited on 27 Islands were of limestone, dominated by Archipelago and Flysch group of rock layers. More than 60% caves are of small size, located in inland forests, below the ground, which lead to downward length from the opening. Around 86% caves had a single opening. We found the cave size varied with the rock layer type, vegetation type and a number of openings. Multiple regression models with different variables showed the type of rock layer as the most influencing factor deciding the cave size in the Islands. This exploratory work, as a baseline study, is a further addition to the knowledge on the scarcely studied hypogene caves in the Andaman Islands.

Introduction:

'Speleogenesis' is the process of origin and development of caves in lithified rocks formed of aggregates of particulate matter (Ford & Cullingford, 1976), determined by the original sediment character and diagenetic history (Challinor, 1967). According to Ford & Cullingford (1976), sedimentary rocks are composed of the remains of plants and animals secreting calcium carbonate during their metabolism, which form the bulk of limestone. Variations in the composition of limestone are due to geochemical and cellular processes. Limestone karsts (a landscape formed from the dissolution of soluble rocks) consist primarily of calcium carbonate formed by calcium-secreting marine organisms millions of years ago before tectonic movements lifted them above sea level (Clements, 2006). Over the years, mechanical and chemical weathering exposes the karsts. Which usually, gives rise to the tower karsts and sinkholes (a hollow in a limestone region that connects with a cavern or passage) or the cockpit karsts (a landscape of star-shaped hollows surrounded by steep, rounded hills, found in tropical karsts) (MacKinnon, 1996).

Poulson & White (1969) defined caves as human enterable cavities on earth (> about 0.6m in width). As per Bunker & Holt (2003), caves must be large enough to get the surveyor fully into the cave, turn around and exit without damaging the attached flora and fauna.

According to Howarth (1983), the subterranean habitat, which is filled either by air or water, can be classified arbitrarily by size as 'microcavern' (<0.1cm in width), 'mesocavern' (0.1 – 20cm) and 'macrocavern' (>20cm). Studies of karst geometric properties have shown that they approximate fractals, displaying a degree of self-similarity at all scales (Verbovšek, 2007; Curl, 1999). The scalar phenomenon, which also appears to be physically true in nature as many ways that scale dependencies could affect the geological processes involved in speleogenesis (Max, 2008). Depending upon the climate, rock strata and biotic factor, caves can vary in size (Howarth, 1983), from few meters to more extensive systems, which extend to hundreds of meters into the rock.

Caves are functional units consisting different species with various levels of specialization and ecological processes that depend on fundamental ecological process and others directly connected to the external environment (Poulson & White, 1969). In the absence of natural light, cave ecosystem depends on the organic materials that fall, wash, wander, or is otherwise brought into caves (Poulson & White, 1969, Peck, 1974; Biswas, 2009). Terrestrial cave community depends on the availability and spatial distribution of the resources (Ferreira *et al.*, 2007). With the limited available and supply of the resources, caves provide subterranean habitat for many species, some of which are wholly dependent on caves for life. Cave

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entrances are strong zonal environments (Howarth, 1993). The subterranean systems receive significant detrital inputs through the entrances. The energy limitation has been considered as the primary constraint/factor, influencing cave community structure, evolution and ecosystem-level processes (Biswas, 2009, Huntsman *et al.*, 2013). However, the relation between the detrital availability and cave community is poorly understood (Huntsman *et al.*, 2013).

Material and methods:

Andaman Islands: the Andaman-Nicobar archipelago, believed to have originated during Late-Pliocene to Pleistocene from a single eruption, extends from the southern strip of Burma to the northeastern strip of the Java-Sumatra trench (Kumar, 1990). The region of the Burmese arc from Arakan including the Andaman Nicobar Islands to Sumatra and beyond is characterized by highly seismic, seismic and aseismic zones with earthquake segments of shallow to intermediate foci in the earth crust (Kumar, 1981; Kumar, 1990). Locations of these islands are in a geosynclinal basin, and frequent tectonic movements resulted in the high folded rocks here.

The strongly folded thrust of the segmented layer is repeatedly removed from the place of deposition. Late submarine flows, Cretaceous ophiolites occur in limestone, sandstone, shale and radiolarite. Acid submarine tuffs occur interbedded in the fossiliferous Lower-Miocene or Post-Pliocene rocks, along with plugs of basic and intermediate lava and agglomerate rocks (Kumar, 1981). The sedimentation is believed to be from the Cretaceous period, and the surface depositions are from sub-recent and the recent past. The oldest sedimentary strata known in the Andaman and Nicobar Islands are the Archipelago group of rocks (Murthy, 2007). This group overlying the late Cenozoic sediments of the Andaman-Nicobar region consists of well-developed marine deposits near Baratang Island of North and Middle Andaman District.

How far the Biospeleology is concerned, the past studies focused on the cave-dwelling birds (Manchi & Mane, 2012; Sankaran & Manchi, 2008; Sankaran, 1998) and bats (Aul *et al.*, 2014). However, limited information is

available regarding speleology of Andaman Islands (Manchi, 2015; Manchi & Sankaran, 2009a; Sankaran, 1991). Sankaran (1998) located and surveyed 384 caves on 37 islands to understand the impact of nest collection on the population of edible-nest swiftlet. The present study was to document the caves in the Andaman Islands and to classify them considering rock layers, sizes, cave openings and the presence of light zones inside.

Most caves in the Andaman and Nicobar Islands fall into two broad categories, (a) those formed by underground drainage and erosion in limestone formations and (b) those formed in sea cliffs by marine erosion of the rocks (Challinor, 1967). The survey was conducted during February and March 2012. Out of the 384 known caves in the Andaman Islands, we could revisit 314 caves. Because of the certain limitation in harsh weather we could not continue to survey the remaining caves. We used Allen (2008) and Pal (2005) to classify the cave areas according to the type of rock layers found in the region; i) Mithakhari group i.e. lensoid conglomerate and sandstone beds in dominantly shale facies (trench sediments) (Chakraborty *et al.*, 1999); ii) Ophiolite group i.e. tectonic (ultramafic)-cumulate (layered mafic and ultramafic) plagiogranite diorite suite basalt pelagic sediments (fossilized oceanic crust) (Gass *et al.*, 1990); iii)

Archipelago i.e. a thick pile of pyroclastic deposits, limestone, sandstone and shale (Ray, 1982); and iv) Flysch i.e. a thick sedimentary pile of sandstone and shale representing classic turbidites (Karunakaran *et al.*, 1964).

Sankaran (1998) followed by Manchi and Sankaran (2009a) and Manchi (2015) had distinguished the caves in the Andaman and Nicobar Islands according to their location of existence. The caves were categorised as; A = On coast, approachable on foot; B = On coast, entrance partially submerged and access by swimming into cave; AB = On coast, approachable on foot after swimming ashore; BD = Cave above sea level on cliff face towards the sea; Ci = In the forest, at the origin of a stream; Cii = In the forest, cavern below the ground; Ciii = In the forest; D = Midway on inland cliff; and E = Japanese bunker (manmade tunnel). We followed the same classification for the present study. The length and height of the cave were

NF: Non Forest, GEF: Giant Evergreen Forest, TEF: Andaman Tropical Evergreen Forest, SHREF: Southern Hilltop Tropical Evergreen Forest, SEF: Andaman Semi-Evergreen Forest, CB: Cane Brakes, SMDF: Andaman Secondary Moist Deciduous Forest, LF: Littoral Forest, MF: Mangrove Forest, MDF: Andaman Moist Deciduous Forest, WBB: Wet Bamboo Brakes, PES: Pioneer Euphorbiaceous Scrub, FP: Forest Plantation, SMDF: Secondary Moist Deciduous Forest

Figure 1: Shapes of the Cave openings in the Andaman Islands .

measured manually using bamboos and Freeman's measuring tape. The caves were then classified as: Very big (>40 m in length), Big (30-40 m length), Medium (20-30 m length), Small (10-20 m length) and Very small (< 10 m length); cave Height: High (> 10 m in height), Medium (5-10 m height) and Short (1-5 m height). We noted the number and shape of each cave opening located (Figure 1). Also, the maximum height and maximum width of each cave opening were measured using Freeman's measuring tape. Following Howarth (1993), by presence of light and its intensity, we divided the caves into following different zones; light zone (LZ; light intensity >50 up to 1800 lux), Dim Light Zone (DLZ; light intensity > 0 to < 50 lux) and Dark zone (DZ; No light zone). We used Digital Lux-Light Meter to measure the light intensity. Vegetation types in the cave areas were classified following Champion and Seth (1968). We separated dry and wet caves according to the presence of water inside the cave. Additionally, we documented the direct and indirect signs of megafauna in the caves during each visit (Howarth, 1930).

We performed chi-square test, to check if the cave size varies with the type of rock layer, forest type, and cave type. Finally, multiple regressions with a forward method were conducted to evaluate how well the cave dimensions and environmental parameters predicted the size of a cave. To assess the combined influence, we incorporated all the factors identified as significant in the first step ($p < 0.05$). We integrated all the qualitative variables into the regression models by creating dummy variables with one category as the reference. For multivariate regressions, we verified the collinearity of the variables with the tolerance criterion. We used IBM SPSS Var. 23.0 for data analyses.

Results:

Of the 384 caves documented on 37 Islands (Sankaran, 1998), we surveyed 304 caves on 27 Islands, along with the new 10 caves found during the study (see Table 1, Map 1). Around 66 % caves had Archipelago (33 %) and Flysch group (33 %) of rock layers, and others had Ophiolite (19 %) and Mithakhari (15 %) types. All the surveyed caves were spread in seven different types of forests (see Map 1, Table 2). More than 60 % of the caves were in Southern Hilltop Tropical Evergreen and Tropical Evergreen Forests. When all these caves were distributed according to their type of location, around 66.45 % of the caves were found located inland while the rest 30.97 % were in the coastal

Figure 2: Cave size, Opening shape and direction of the length inside the caves at the Andaman Island

Figure 3: Cave structure-showing cave opening shape & length direction of different size caves at Andaman Island

Figure 4: Zonation of the caves in Andaman Islands by presence & intensity of light.

areas. Of the total surveyed caves, 61.49 % were of Cii-type (in the forest and below ground) followed by 23.58 % of B-type (On the coast, entrance partially submerged and access by swimming into the cave). Less than six percent (5.97 %) caves were of AB (On the coast, approachable on foot after swimming ashore), A (On the coast, approachable on foot) and BD (Cave above sea level on cliff face towards the sea) types. The caves in the Andaman Islands were of different sizes. Most caves were of Small (40.76 %) and Very Small (22.61 %) size (Fig.-1). The size of the caves varied with the cave type ($\chi^2 = 45.77$, $df = 8$, $p < 0.001$, $N = 334$), forest type around the cave ($\chi^2 = 82.75$, $df = 12$, $p < 0.001$, $N = 319$) and the rock layer type ($\chi^2 = 116.58$, $df = 12$, $p < 0.001$, $N = 335$). Of the total, 28.90 %, 24.31 % and 24.31% caves were with Circular, Arch and Triangular shape of openings respectively (Fig.-2). Maximum caves (86.24 %) had a single opening, followed by the caves with two openings (10.09 %). Very few caves (3.67 %) had three openings. Immediately after the openings, 60% caves extend downward, and 38.53 % caves extend in a horizontal direction, while very few (0.92 %) proceeded upward (Fig.- 3). More than 80 % caves were totally dark, whereas less than 10 % caves were of an open type having dim light zones inside (Fig.-4). Multiple regression models with all variables depicted that the formation of different sizes of caves is highly influenced by the rock layer type existing in the various regions followed by dim light zone and number of cave mouths (Table-3).

Discussion:

In the Andaman Islands, pyroclastic deposits and turbidites are made up of a thick pile of the limestone,

Table 1: Classification of the caves in the Andaman Islands

Island Name	Number of caves	Caves surveyed	Cave Size					Cave Type						Rocks Layer
			VB	B	M	S	VS	A	AB	B	BD	Cii	D	
Chalis-ek	35	35	4	5	6	20	0	1	0	0	0	4	30	Mk
Chidiya Tapu	1	1	0	0	0	1	0	0	0	1	0	0	0	Opl
Cuthbert Bay	3	3	0	0	0	3	0	0	0	3	0	0	0	Mk
East Is.	1	1	0	1	0	0	0	0	0	1	0	0	0	Arh
Henry Lawrence	20	20	0	0	5	15	0	0	0	20	0	0	0	Arh
Inglis	2	2	0	0	0	2	0	0	0	2	0	0	0	Arh
Interview Is.	35	35	1	2	4	28	0	0	13	0	0	22	0	Arh
Jarawa Main	2	0	NS	NS	NS	NS	NS	0	0	2	0	0	0	Flh
Jarawa Is. 1	1	0	NS	NS	NS	NS	NS	0	0	1	0	0	0	Flh
Jarawa Is. 2	2	0	NS	NS	NS	NS	NS	0	0	2	0	0	0	Flh
Jarawa Is. 3	1	0	NS	NS	NS	NS	NS	0	0	1	0	0	0	Flh
Little Andaman	4	0	NS	NS	NS	NS	NS	0	0	4	0	0	0	Opl
Middle Button	1	1	0	0	0	1	0	0	0	1	0	0	0	Arh
Neil	9	9	0	1	8	0	0	0	0	9	0	0	0	Arh
North Cinque	1	0	NS	NS	NS	NS	NS	0	0	1	0	0	0	Opl
Opposite Strait	1	1	0	0	0	1	0	0	0	1	0	0	0	Flh
Outram	3	3	0	0	0	3	0	0	0	3	0	0	0	Arh
Passage	2	0	NS	NS	NS	NS	NS	0	0	2	0	0	0	Flh
Point	2	2	0	0	2	0	0	2	0	0	0	0	0	Mk
Ramnagar	3	3	0	0	0	3	0	0	0	3	0	0	0	Opl
Redskin	1	0	NS	NS	NS	NS	NS	0	0	1	0	0	0	Flh
Reef	5	5	0	0	2	3	0	0	0	0	0	5	0	Arh
Rutland	5	0	NS	NS	NS	NS	NS	0	0	5	0	0	0	Opl
South Button	14	14	0	0	0	14	0	0	0	14	0	0	0	Arh
Strait	2	0	NS	NS	NS	NS	NS	0	0	2	0	0	0	Flh
White Cliff	4	0	0	0	4	0	0	0	1	0	3	0	0	Mk
Wrafter's Creek	175	175	15	20	35	34	71	0	0	0	0	175	0	Flh
Total Islands 27	335	310	20	29	66	12/8	71	3	14	7/9	3	20/6	30	

[A = on coast approachable on foot; B = on coast, entrance partially submerged and access by swimming into cave; AB = on coast, Approachable on foot after swimming ashore; BD = Cave above sea level on cliff face ending in the sea; Cii = in the forest, cavern bellow the ground; D = Midway on inland cliff. VB = Very big, BG = Big, M = Medium, S = Small, VS = Very small, NS = not surveyed cave, Mk = Mithakhari group of rock layers, Opl = Ophiolite group, Arh = Archipelago group, Flh = Flysch group]

Table-2: Vegetation types surrounding the surveyed caves in the Andaman Islands

♦Forest type combination	A	B
♦Moist Deciduous	MD	1
♦Moist Deciduous, Secondary Moist Deciduous	MDSMD	4
♦Moist-Deciduous, Tropical Evergreen	MDTE	20
♦Moist Deciduous, Secondary Moist Deciduous, Semi-evergreen	MDSMDSE	4
♦Secondary Moist Deciduous	SMD	24
♦Secondary Moist Deciduous, Tropical Evergreen	SMDTE	9
♦Secondary Moist Deciduous, Semi-evergreen	SMDSE	13
♦Semi-evergreen	SE	11
♦Southern Hilltop Tropical Evergreen	SHTE	5
♦Southern Hilltop Tropical Evergreen, Tropical Evergreen	SHTETE	197
♦Southern Hilltop Tropical Evergreen, Semi-evergreen	SHTESE	35

A- Forest types & Class; B- Number of Caves.

sandstone, and shale under the true tropical environment (Kumar, 1990; Kumar, 1981). Therefore, most of the caves surveyed were located in the Evergreen Forest with Archipelago and Flysch rock groups. The limestone caves are formed by the impact of water on the rock layers (Clements et al., 2006; Poulson & White 1969). It simply explains the relationship between the type of rock layer and formation of limestone caves. It is also explained by the variations in the cave size according to the change in the rock layer type in the Andaman Islands. Further evolution of these caves depends upon various other factors like rainfall, water runoff, water percolation and its interaction with the environment inside the caves. The forest type plays a significant role in maintaining the soil cover and the terrain, which further controls the amount of water entering the cave via percolation or the cave openings. Although not yet formally documented but from our field experience we understand that the forests in the rocky terrain are less disturbed. Fortunately, since the limestone areas have difficult terrain, forest in most of

Table 3: Result of multiple regression analysis (Forward type) for predicting size of the caves in Andaman Is.
Multiple regression equation: Cave size = -2.402 + 1.106 (Rock layer) - 2.387 (cave mouth 3:door shape) - 0.525 (cave mouth 9: circular shape) - 0.186 (cave mouth width in meter) + 0.429 (dim light zone) + 0.524 (number of cave mouths)

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Correlations			Collinearity Statistics	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
(Constant)	-2.402	.864		-2.781	.006	-4.104	-.699					
Rock layer type	1.106	.196	.348	5.635	.000	.719	1.492	.317	.365	.328	.892	1.121
Cave mouth shape 3: door	-2.387	.628	-.228	-3.803	.000	-3.624	-1.149	-.236	-.256	-.222	.944	1.059
Cave mouth shape 9:circular	-.525	.188	-.168	-2.795	.006	-.895	-.155	-.118	-.191	-.163	.941	1.062
Cave mouth width	-.186	.076	-.155	-2.440	.016	-.337	-.036	-.149	-.168	-.142	.838	1.193
Dim light zone	.429	.179	.149	2.396	.017	.076	.782	.297	.165	.140	.874	1.144
Number of cave mouths	.524	.185	.172	2.834	.005	.159	.889	.287	.194	.165	.916	1.092

Adj R²= 0.280; F=14.774; p<0.001

these regions could not be logged, because of the inaccessibility. Moreover, human activities here are less, resulting in the preservation of the Tropical Evergreen and Semi-evergreen Forest.

The Andaman Islands mostly have the dark caves with a single small opening. The small openings of the cave do not allow much interaction between the inside and outside environment and also restrict the entrance of light. For a hypogene (underground) environment, the major nutrient sources are the physical and biological agents immigrating from the epigene (at or near the surface) environment (Culver, 1982). Closed caves, because of almost no light, are usually the home for the troglobitic (obligatory terrestrial animals exclusive to dark zones of caves) and stygobitic (obligatory aquatic animals exclusive to dark zones of caves) fauna. These caves may be the home for the endemic flora and fauna with high conservation value (DENR-PAWB 2008). Visits of the nocturnal animals to these regions are not yet explored. The open caves with different zones (light zone, dim-light zone, and dark zone), as per presence of light, allow visits of different epigean fauna and growth of photosynthetic organisms, which acts as the source of nutrition in the cave ecosystem.

The cave entrances are the ecotone regions (a transition zone between epigean and hypogene system) with gradients in structure, biological or physical modifications, where environmental variables are under strong influence from the external and internal environment (Prous *et al.*, 2015; Prous *et al.*, 2004). Therefore, understanding the cave entrance and its role in moulding and maintaining the biodiversity and ecosystem inside is important. Studies in ecotones with the terrestrial approach are meager (Lunghi *et al.*, 2014; Gilbert *et al.*, 1990). Cave systems that are well connected to the outside environment through more entrances or sinkholes can receive significant detrital inputs, whereas caves with few entrances typically have reduced detrital inputs. The energy limitation due to this is considered as

the primary constraint influencing cave community structure, evolution and ecosystem-level processes (Huntsman *et al.*, 2011).

Presently, our knowledge about the caves in India is mostly limited to the cave paintings, the archaeological importance of caves and some geological and faunal surveys in caves. Whereas, in the Andaman and Nicobar Islands the knowledge of caves is limited to the cave-dwelling bats (Aul *et al.*, 2014) and birds (Manchi & Sankaran, 2014; Manchi & Sankaran, 2009b). The fundamental results of the present study regarding the rock type, cave type, cave size, cave location and cave openings is a stepping stone towards a better understanding of the biotic and abiotic factors of the limestone caves in the Andaman and Nicobar Islands.

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