INTERNATIONAL JOURNAL OF ENVIRONMENT

Volume-3, Issue-2, Mar-May 2014 **ISSN 2091-2854**

Received:13 April *Revised:1 May* *Accepted:16 May*

ENVIRONMENTAL CONDITIONS OF BORRA CAVE, VISAKHAPATTANAM, INDIA

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Abstract

Caving is an art which can be best experienced in the mystic Borra of Eastern Ghats and ranked as the second largest cave of India just after Belum Caves situated in the same state Andhrapradesh, India. This Cave is fast becoming a hot tourist's destination offering great adventurous opportunity to the tourists in the Eastern Ghats. The cave is located in the Ananthagiri hills of the Eastern Ghats region near Visakhapattanam and is made of limestone. The emotion of thrill heightens after entering the cave. The entrance has a narrow vertical opening and is well lit. Due to its location in the sub-equatorial region, dripping of water from the cave roofs occurs almost throughout the year. The formation of stalactites and stalagmites create wonderful phenomena specially found in this cave. The conspicuous pillars formed due to the joining of the roof and the floors are an awe-inspiring creativity of the creator of this world. Various viruses and bacteria are in the cave interior along with different other creatures. The Borra cave helps the Govt. of Andhra Pradesh, India, to earn huge economic benefits for the sake of tourism industry.

Keywords: Cave, stalactite, stalagmite, virus, bacteria

Introduction

Caves have always hunted the imagination of mankind already from the start of human history; these natural formations provided shelter to early man and were sought after earnestly, to provide a 'safe home'. Caves are natural habitats for a wide spectrum of fascinating life forms. Caves offer natural, experimental study system of the subsurface for fundamental geomorphologic studies (Baskar et al., 2009). The civilized people like to visit the caves for its scenic beauties.

There are so many caves in India made of limestone enhancing scenic beauties**.** In India, The Telugu persons live at Andhra Pradesh calls the Borra Cave as '**Borra Guhalu'.** In telugu language 'Borra' means something that has bored into the ground and 'guhalu' means caves. The

Cave is the second largest cave (just after Belum Caves, Andhrapradesh, India, length: 3,229 m) extending to a length of 625m (2,051 ft) and wide of 83m(249 ft) in the country, distinctly exhibit a variety of impressive speleothems (pictured) ranging from very small to big and irregularly shaped stalactites and stalagmites. A cave is a natural opening or cavity within the earth, generally extending from the earth's surface to beyond the zone of light (Davis, 1969). An opening connected to the surface can have three major zones based on light penetration and intensity: (i) the entrance zone, which is exposed to full sunlight and experiences the daily light cycle; (ii) the twilight zone; and (iii) the dark zone, where no light penetrates (Figure 3).Different types of life, and subsequently adaptations expressed by that life, are generally correlated to these zones because of specific physico-chemical and geochemical conditions related to photic gradients. Entrance and twilight zone conditions are tolerable to a wide variety of organisms, from insects to vertebrates, with little modification to their overall lifestyle (Lee et al., 2012).

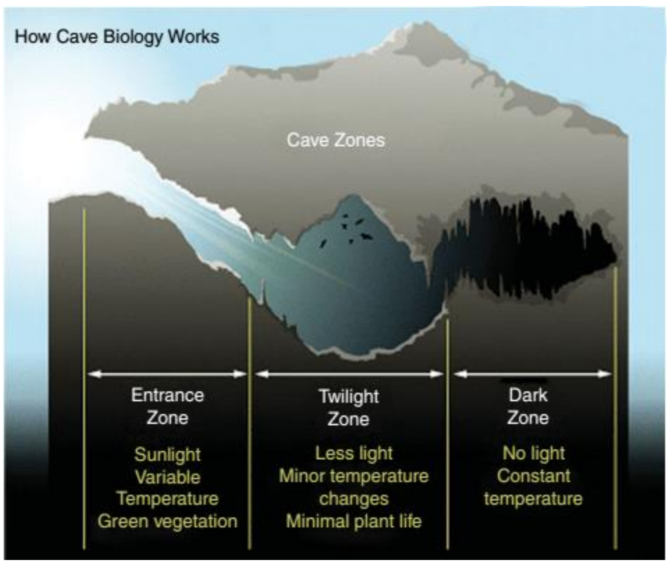

Figure 1. Light zones of the Cave

The Cave is basically Karstic limestone structures extending to a depth of about 80 m may be considered as the deepest cave in India. In 1807, William King George of the Geological Survey of India discovered the caves (Kar, 2001). It is also one of the important hill regions of the Eastern Ghats and known not only for the diversity of its flora and fauna, but also for the richness of its minerals. The caves have an archaeological importance due to the discovery of some Palaeolithic implements. These caves host a variety of speleothems ranging from very small to big and irregularly shaped stalactites and stalagmites.

Location

The very significant Borra cave is located on the East Coast of India, in the Ananthagiri hills of the Araku valley. In the state Andhra Pradesh of India, the Vishakhapatnam District (Figure 2 & Figure 3) is situated in the coastal region along with Eastern Ghat Hills. The Ananthagiri hills are the parts of the Eastern Ghat Hills situated in the North-Western region of Vishakhapatnam District. The Borra Caves are situated in the Araku Valley, approximately 90-

95 km form Visakhapatnam and lies in the reserved forest area. The Borra cave is in the North-Western foothill region of Ananthagiri ridge belongs to the Borra village. The latitude of the cave is 18°10′N and the longitude is 83°0′E. The Borra Caves lie in the reserved forest area and consist of 14 villages inhabited byribals in the Ananthagiri Mandal of Visakhapatnam district.

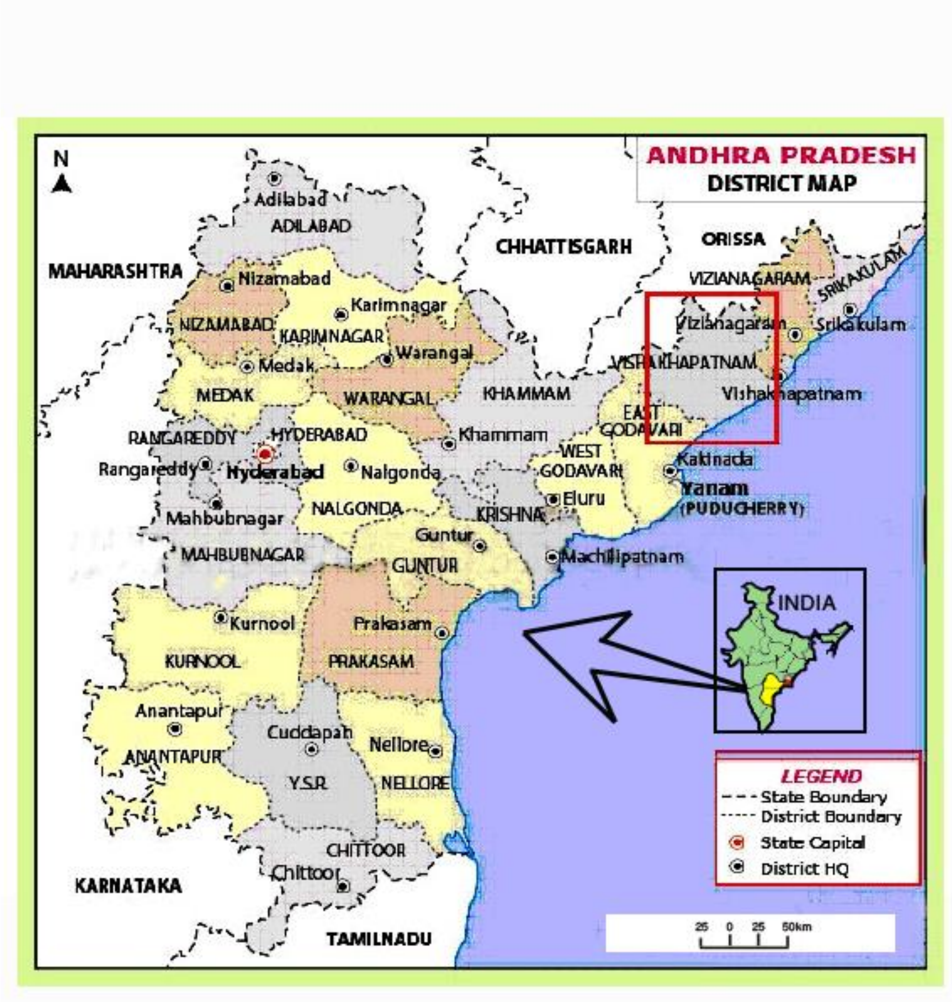

Figure 2. Location of Visakhapattanam District, Andhrapradesh, India

Figure 3. Location of Borra Cave at Visakhapattanam District, Andhrapradesh

Legendry

There are several legends related to the discovery of the cave narrates by the tribals (Jatapu, Porja, Kondadora, Nookadora, valmiki etc.) who inhabit the villages around the cave. The most popular and superstitious legend is that a cow, grazing on the top of the cave, dropped 60 m, through a hole in the roof. The cowherd of the neibouring village came across the caves while he was searching for his missing cow. He looks down the cave and found a stone inside the cave that resembled a *Lingam*. Owing to his highly superstitious mentality he interpreted the very significant stone as the Lord Shiva and also believed that the cow was protected by Lord Shiva. The villagers who heard the story believed it and since then they have built a small temple for *Lord Shiva* outside the cave. Some Hindu people visit the temple for worship and the cave to get a glimpse of the *Lingam*.

Plate 1. Siva-Linga, the symbol of Hindu God Lord Shiva

Another lyrical legend is that the *Shiva Lingam* (Plate 1) representing the Hindu God Lord Shiva, is found deep in the cave and above which is a stone formation of a cow (Sanskrit: Kamadhenu). It is surmised that the udder of this cow is the source of the Gosthani (Sanskrit: Cow's udder) River which originates from here, flows through Vizianagram and Visakhapatnam districts before debouching into the Bay of Bengal near Bheemunipatnam.

Materials and methods

Direct field observation is the principal methodology of the study. A team of geographers had visited the cave during the month of October, 2013. The characteristics of the cave and significant phenomenon are studied and included to draw attention of the future researchers. The information about the geological structure is collected from the secondary data sources whereas the socio-economic data are collected from the local people. The environmental conditions are also studied directly from the field observations and to some extent collected from the secondary sources also. The tourist guides had helped a lot to visit the surrounding regions of the cave and added information which are very significant and interesting for the researchers. Information, mainly related to legendary, are also collected from different secondary sources as it was in various web sites. The distinct study had never been done about the cave in the past.

Results

Geology

The geology of this region is represented by the Khon-dalite suite of rocks (garnetiferrous sillimanite gneisses, quarto-feldsphatic garnet gneisses) of Archaen agein the Eastern Ghats mobile belt. Quaternary deposits consist of red bed sediments, laterites, pediment fans, colluvium, alluvium and coastal sands .All these rocks lie within calc-silicate granulites and garnet-sillimanite gneisses (khondalites) which have been repeatedly folded and metamorphosed at high grades and form a part of the Eastern Ghats granulite belt. The charnockite patches that occur within leptynite host, in and around Jenapore, northern sector of the Eastern Ghats granulite belt, are disposed in a linear fashion and generally have sharplithological contact with the host leptynite (Kar, 2001).

Detailed field observations, petrographic studies and mineral assemblages have been considered in arriving at the evolution of Borra carbonate rocks produced by metamorphism of limestone. The rock type in the area includes khondalites and charnokites belonging to the granulite grade metamorphism. The repetition of the khondalitic and charnockitic rocks in the Eastern Ghats is due to the tight isoclinals folds present in the mobile belt. An overturned anticline (Figure 4) is recognized based on the general attitude of the beds and strike and dip directions of foliations. The present studies on the Landsat Imagery revel that the Borra anticline is part of doubly plunging anticline around Anantgiri.

The calcite marbles frequently occur as minor patches and bands, and are inter bedded with the Garnet-sillimanite gneisses. The major calcite marble unit, in an extensive scale, is exposed around Borra and bordered by calc-granulite and diopsidities. The ubiquitous occurrence of garnet-sillimanite gnesses as layers and lenses within the marbles and vice versa indicate that these litho-units are gradational and confirm the metasedimentary sequence. The refolded nature of the migmatized cal-granulites, diopsidities and ganet-sillimanite gneisses indicate that these metasediments have suffered the same deformation. The early deformation (F1) in the khondalites has affected lithological layering and the major structures (asymmetrical to isoclinals folds) are formed during the F2 shear folding in a regional way giving rise to dominant NE-SW trend. The superimposed NW-SW trend, due to refolding has resulted in open upright SE plunging folds F3 often resulting in domal structures which could be partly due to the interference of F2 and F3 folds (Figure 4).

The calcite marbles free of impurities confined to the inner zone in the carbonate rocks also show signs of migmatization in the mode of rhythmic bands of dolomites and calcites. Agmatite-like structures exhibited by dolomite in the coarse crystalline calcites are not uncommon.

The white dolomites are medium-grained and contain mosaic of dolomite with accessory calcite localized in the intergranular spaces. The pure coarse crystalline calcites occur in the sheds of white, yellow and blue and are characteristic with rhombohedral cleavage (Rao, 1989).

The carbonate rock at Borra is pure white, and coarsely crystalline.At Borra, deformed and banded marbles extend over a triangular area of 2 sq. km. They are surrounded by diopside-scapolite-feldspar calc-granu-lites **(**Lange, 1977). The pyroxenite outcrops at Borra are dark and massive and include discontinuous calc-silicate bands, some of brown mica and others with calcite (Figure 5).

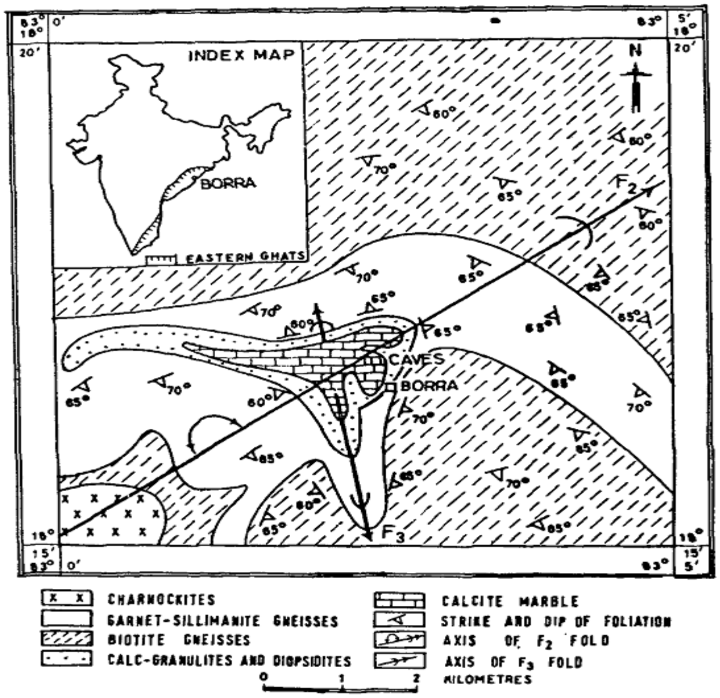

Figure 4. Geological Map of Borra Cave area, Visakhapattnam District, AP, India (Rao, 1989)

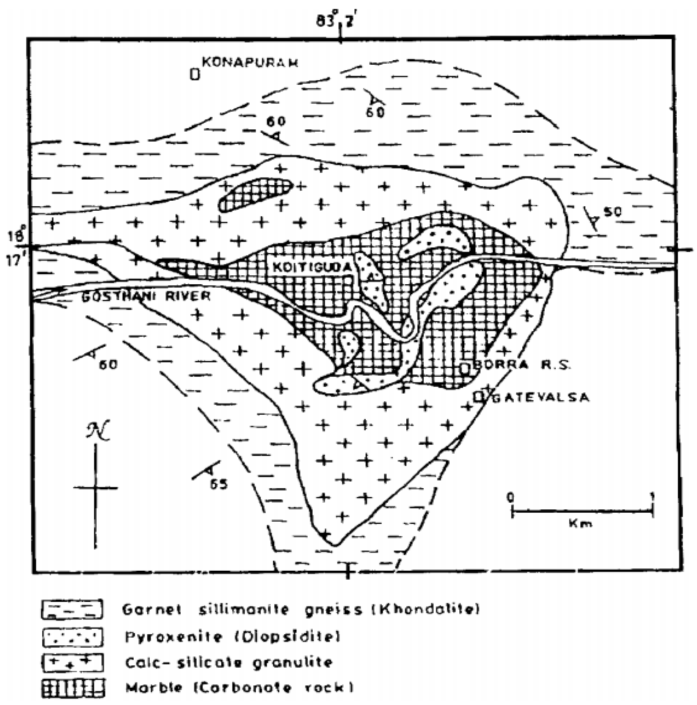

Figure 5. Geological map of the Borra area. Blank areas are Quartzo-feldspathic gneisses. R.S. Railway Station (Baskar et al., 2007)

Genesis of the Cave:

Three generic classes of caves can be recognized according to the major sculpturing process: (1) caves formed by pressure or flow, (2) caves carved by erosion, and (3) caves dissolved by solution. The caves dissolved by solution are the familiar limestone caverns or caves. Limestone caves are, by far, the most common type of caves.

Due to presence of limestone in its womb cave formation in the Anantgiri Hills begin when rainwater absorbs carbon dioxide as it falls through the atmosphere. Rain water must have carbon dioxide to become acidic. It must be acidic to chemically react to the limestone bedrock. Rainwater is absorbed by the soil into the ground. These factors influence on the Pressure-Temperature in this region which helps to determine the factors of cave formation.

For these aforesaid reasons rainwater comes through the soil absorbs more carbon dioxide that is being produced by plants that are dead. This changes the ground water to a weaker form of carbonic acid ($H_2O + CO_2 = H_2CO_3$). As it travels down through the ground it comes to solid rock (Jones, 2010). When the rock is limestone or dolomite caves can form. Solution cave chemistry can be simply stated: limestone and dolostone, the host rocks for most caves, are dissolved by natural acids (carbonic, sulfuric, and various organic acids) which occur in groundwater (Lee et al., 2011). Calcite ($CaCO_3$), the principal mineral comprising limestone, is dissolved in the presence of acid to produce calcium ion (Ca^{++}) and bicarbonate ion (HCO_3^-). Dolomite [$CaMg(CO_3)_2$], the most important mineral in dolostone, is dissolved by acid to produce calcium ion (Ca^{++}), magnesium ion (Mg^{++}), and bicarbonate ions (HCO_3^-). If the acid is able to flow through the rock, ions will be removed and a cavity or solution conduit will form (Figure 6).

In low-water conditions during the dry season, airflow through the cave conveys oxygen and soil runoff brings in iron. Oxidation of the iron by bacteria, such as Leptothrix sp., biomineralize FeOOH as encrusting sheaths and form a biofilm at the water surface. Simultaneous degassing of CO2from cave waters and the release of CO2 by organic respiration enriches the pCO2of the cave air. Reduced pCO2 in the water and high levels of and dissolved Ca2+and HCO3-from the UFA promote calcification of the biofilm (Lee et al., 2012).

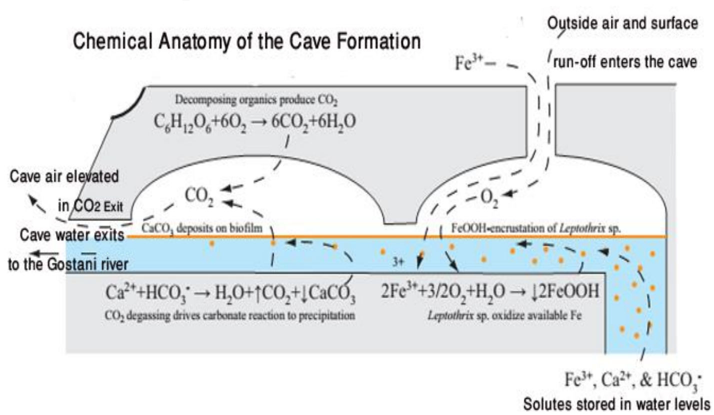

Figure 6. Possible Chemical Reaction inside the Cave

The water reacts chemically with limestone and slowly a larger and larger space will form. This happens because the rocks are made of calcium carbonate ($CaCO_3$). This is what you call chemical erosion. As the space becomes larger and larger the water can flow through. As it flows it erodes. Physical erosion washes away rock and sand (Singh, 1997). This is what makes a cave larger and forms an underground stream. Finally over hundreds of thousands of years or even millions of years the cave is formed (Figure 7).

Two basic types of theories concern the water conditions when the cave formed. These are the *vadose* and *phreatic* theories. The vadose theory suggests that solution of the cavity occurred while the limestone was above the level of groundwater (water table) and that the cavity was largely filled with air. The phreatic theory claims that the cavity formed when it was below the level of groundwater when it was completely filled with water (Austin, 1980). Anantgiri Hills consist higher altitude and limestone in the surface and subsurface zone. Thus it can be assumed that the Borra cave is formed according to the Vadose theory. The historic records show that Gosthani was once a famous river of the place which was characterized by huge deposits of limestone. With the passage of time, the minerals of the place started to suspend due to the continuous flow of water. This in turn led to the formation of the famous Caves.

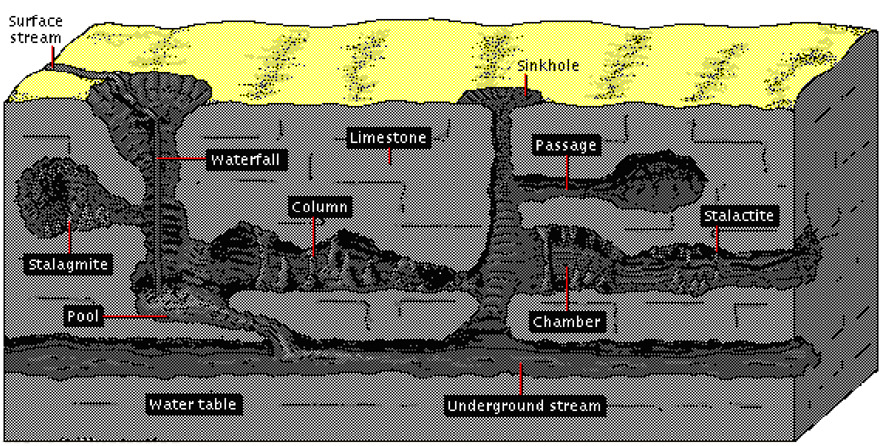

Figure 7. General Outline Related to Formation of Borra Cave

Physiography

Borra cave is situated in the Ananthagiri hills of the Araku valley. The elevation of the entire Ananthagiri hill varying from 800 m to 1,300 m which belongs to the Eastern Ghat ranges. Borra cave is situated at an elevation of about 705m from the mean sea level(m.s.l).The opening of the cave measures up to 110 m horizontally and 60-70 m vertically. The deep cave is totally aphotic. The stalactites ranged in lengths from approximately 1.4 to 3.6m. The stalagmites are around 1 to 1.3m long.

Plate 2: Bora Cave Mouth

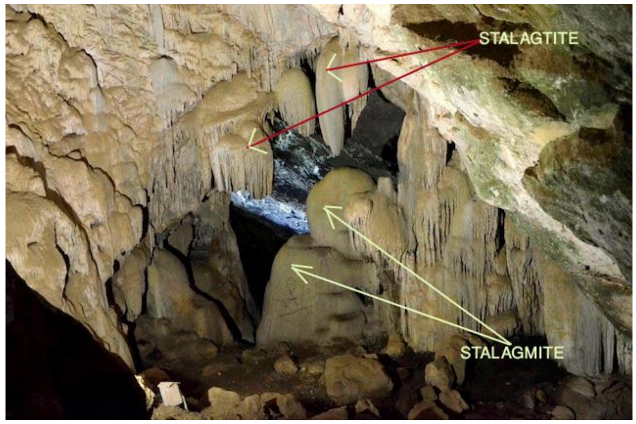

Plate 3: Limestone Landforms of the Cave

Drainage

Between the solidified stalactites and stalagmites is the Gosthani River which flows out of the caves. The Gosthani rises in the Ananthagiri Hills of the Eastern Ghats and flows through the Borra Caves which lie near its source. It flows for 120 km before joining the Bay of Bengal through an estuary near Bheemunipatnam. The river basin drains the two coastal districts of Vizianagaram and Visakhapatnam. The basin river network exhibits a subdendritic and dendritic pattern of drainage. The Gosthani's is a minor river basin with a total drainage area of less than 2000 km^2. Much of the basin is covered by khondalite group of gneissic rocks. About 3% of the total area of the Visakhapatnam district is under the Gosthani basin. The river is rain fed, receiving an average rainfall of 110 cm most of which comes from the south-west monsoon. There are several red sand hills near Bheemunipatnam, where the Gosthani joins the Bay of Bengal, which are reminiscent of the Chambal ravines. These are thought to have been formed six millennia ago due to shifts in the river's course following tectonic activity. The river joins the Bay of Bengal at Bhimli where it forms an estuary.

In the Borra cave region there are several rills and gullies. The small rills and gullies are flowing over the roof and due to seepage the water penetrates down through the roof of the cave. The seepage is continuing hours and hours from the roof and drops down to the floor of the cave due to its location in the world’s highest rainfall region. The water is percolating down the towards the ground. Somewhere the water remains stagnant in the cave floor. In the cave floor so many rills and gullies are formed which are coming down through the cave wall as spring.

Plate 4. Orange organic mat of Spring in the floor of Borra Cave (Baskar, 2007)

Climate

The annual temperature of Araku Hills is approximately 25°C and annual rainfall is 950 mm (mostly coming from the northeast monsoon). In the Cave interior temperature becomes higher upto 40°C. The humidity increases upto 92% and water droplets leach down from the roof of the cave at almost regular intervals.

Waterworks

The Gosthani's waters are diverted for agricultural and industrial purposes and the river is the chief source of drinking water to the cities of Vizianagaram and Visakhapatnam. Several infiltration wells have been sunk on the Gosthani's riverbed to extract water especially during the summer months. The Thatipudi Reservoir Project with a capacity of 3 *thousand million cubic* (TMC) was built on the Gosthani during 1963-68 and is located in the Gantyada Mandal of the Vizianagaram district. It irrigates 15,378 acres (62.23 km^2) of land in Vizianagaram district and provides drinking water to Visakhapatnam. The Chaparai Falls, situated in a verdant valley, is on the Gosthani river. The Visakhapatnam to Srikakulam leg of the Golden Quadrilateral Highway crosses the Gosthani at Tagarapuvalasa where a new bridge was inaugurated in 2003.

Environmental issues

The decision to grant bauxite mining leases in Visakhapatnam by the Government of Andhra Pradesh has drawn criticism from local people, activists and the Central Government who fear severe environmental damage along the source and catchment areas of the river due to the mining. The decision to lease out the Gosthani's river bed to a private company for the extraction of groundwater through the sinking of borewells is thought to have had serious consequences on the water table and water security of over 100,000 people in the region.

Biological environment

In the cave the flora and fauna are with unique varieties. Due to insufficient light inside photosynthesis does not occur and plants are found only in the cave entrance. Some fungi do well in the cave. The artificial electricity which are projected to make it show cave for the visitors helps to alive and growth of some mosses, algae and ferns. Crustaceans ranging in size from tiny copepods to large crayfish are found inside the cave. The fauna observed in the caves are predominantly bats, as well as the golden gecko. The type of bat reported is the fulvous fruit bat (Rousettus leschenaultii) – a species which roosts in large caves, old buildings, dungeons and dark areas of old forts. This species has short and slender musculature with large, well developed eyes. The other fauna like crickets, cockroaches, insect larvae, birds, cave beetles, spiders, worms, snails, millipedes, centipedes and cave rats are also found inside the cave. They feed on flowers and fruits, particularly jamun, guava, silk, cotton and mango present outside the cave.

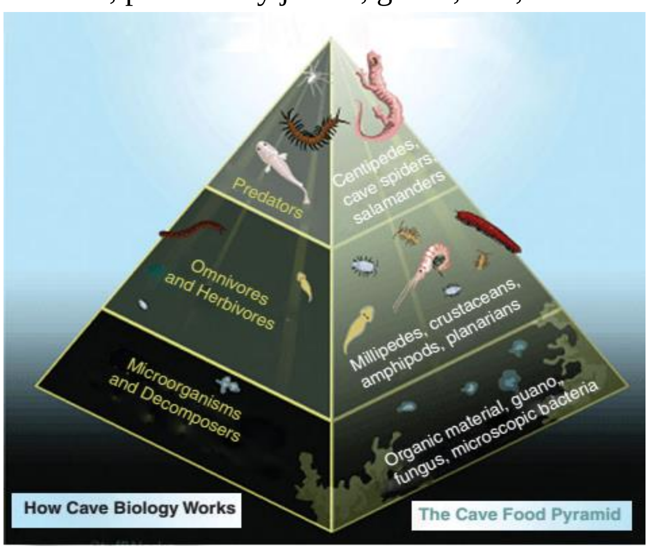

Figure 8. Cave Food Pyramid

Depending on the available energy source over time and the survival ability of the species, different types of adaptations (Figure 8) in response to the cave environment are likely to have taken place for at least certain species. A good example of this are microbial species that adapted metabolically to a strict chemolithoautotrophic life style, living off inorganic compounds present in the rocks and groundwater, such as metals, sulfur and methane (Engel, 2010). Other examples include higher organisms that adapted to the subterranean environments via various metabolic and morphological adaptations, such as pigment loss, eye loss, wing loss, reduction in size, development of more sensitive sensory organs, limb extension, reduction in metabolic rates and increased longevity (Culver and Pipan, 2009; Romero, 2009). Interestingly, a broad taxonomic range of organisms obligately adapted to the subsurface, in either terrestrial (troglobionts) or aquatic (sytgobionts) habitats, share this suite of characters, referred to as troglomorphy. These obligate subsurface organisms generally also have 330 N.M. Lee et al.limited possibilities for dispersal, which can further constrain genetic populations to local, and rarely regional, hydrostratigraphic regions.

Microorganisms

Viruses are the most abundant type of 'biological entity' on Earth, being found wherever there is life, and have probably existed since the first cells evolved. Viruses are capable of infecting all types of organisms, from prokaryotes to plants and animals (Abedon, 2008). There are a few, sporadic reports of high abundances of viruses in various extreme environments or caves, with at least three related categories of case study pointing toward the potentially high significance of viruses in caves: (i) many prokaryotes in various types of extreme ecosystems are in general attacked by viruses (Rainey and Oren, 2007); (ii) large numbers of novel viruses have been detected in the subsurface and are thus postulated to play a crucial role (Kyle et al., 2008); and (iii) several infectious viruses have been reported from caves, in particular from animals like insects or mammals residing in caves. A classic example of this comes from bats: the animals may themselves be attacked by viruses, such as the West Nile virus, or alternatively serve as significant reservoirs of viruses that infect humans and other animals, e.g. emerging zoonotic viruses, such as lyssaviruses, filoviruses and paramyxoviruses. Furthermore, most of the outbreaks of hemorrhagic fever caused by the lethal Marburg virus in humans and associated with visits to cave like Bora (Kuzmin et al., 2010). Thus, research into the unique, isolated ecosystems presented by caves may yield many interesting and relevant insights into a number of other biological disciplines (Lee et al, 2012). West Nile virus is a mosquito-borne disease that can cause encephalitis, a brain inflammation for human. Infected mosquitoes pass the virus onto birds, animals and people. More severe disease due to a person being infected with this virus can be "West Nile encephalitis," West Nile meningitis or West Nile meningoencephalitis. The *Marburg virus* causes severe viral haemorrhagic fever in *humans.*

The prokaryotes, which comprise the domains Bacteria and Archaea, are the most abundant group of organisms on our planet. The first microbiological studies in caves were performed in the late 1940s using predominately microscopy and enrichment techniques, and these approaches continued for almost three decades. Many different types of biogeochemical reactions driven by microorganisms have been observed from distinct ecological cave zones (e.g. ammonification, denitrification, nitrification, sulfate reduction, anaerobic sulfide oxidation, metal oxidation, metal reduction, methane cycling, photosynthesis; Engel, 2010). Precipitates of biological origin produced by various cave bacterial species amongst which biogenic iron precipitated by a dense microbial community on Leptothrixsheaths, Borra caves, India. The effect of microorganisms in the mats on the cave formation and their role on iron mineral precipitation has been further studied. A report by Sushmitha Baskar et al., 2007 indicates a link between iron–rich mats formation and iron precipitating bacteria.

The abstract of their report states:

The spring waters (pH neutral 7.5–7.7) contained dissolved metals like iron and the organic mat sludge (pH 7.0–7.3) had a TOC content of approximately 5.4 wt%. Geochemically, the spring waters deep below the microbial mats contained Fe 369 ppb, Sr 198 ppb; and the organic mat sludge contained Mg 9 ppm, Fe 427 ppb, Zn 149 ppb, Sr 190 ppb. XRD observations displayed Fe minerals (dominantly hematite), minor amounts of zinc gallium sulfide and nitrofuryl compounds. At least four groups of bacteria identified by direct microscopy and SEM-EDX on the basis of morphology could be observed in all samples: Leptothrix–like organisms, entombed bacterial mineral sheaths, a few stalks of Gallionella–like organisms and some additional bacteria that could not be further identified. Leptothrix–like organisms contained 43.22–60.08 wt % Fe and the mineral precipitated near and around these bacteria (in the actual unaltered samples on site) contained 30.76–45.22 wt% Fe as identified and quantified by SEM-EDX. The surface of the Borra cave, chemolithoautotrophs and heterotrophs play different ecological roles. Extreme environmental conditions also influence the metabolism of oligotrophic, acidophilic, thermophilic and/or sulfidophilic species. Different types of growth patterns may be observed, including single-celled, planktonic life stages to impressive aggregates, such as biofilms, forming either massive microbial mats on cave springs or pools or microbial draperies ('snottites') on cave wall surfaces.

a) b)

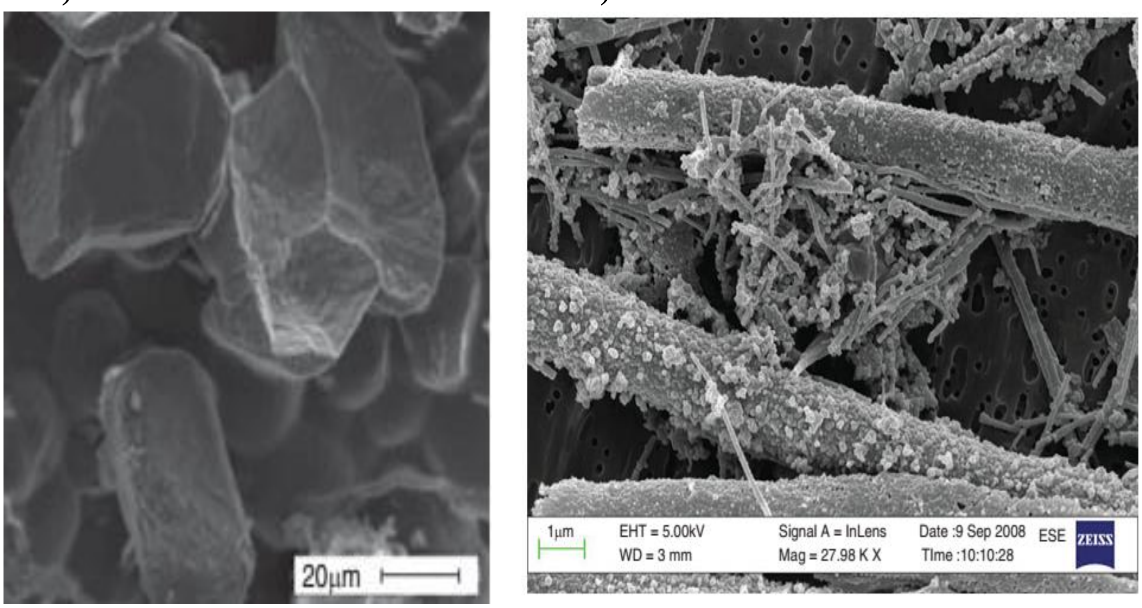

Plate: 5, 6: Precipitates of biological origin produced by various cave bacterial species: (a) biogenic iron precipitated by a dense microbial community on Leptothrixsheath and b) Calcium carbonate precipitate. Calcite crystals precipitated in vitroby Bacillus pumilis Borra caves, India (Lee et al. 2012)

Socio-Economic Impact

In Old Testament times caves often served as refuge or emergency shelter. Caves are of interest to the student of the Bible because the Bible lands are rich in limestone caves (Austin, 1980). The great size and beauty of the limestone caves like Borra have made them features of public amazement and wonder. In the interior of the cave people emarginated different stalactite and stalagmites as the '*Shiva Linga'* or sometimes as the '*Ganesh*'. The *Jatapu* or *Porja* people have their superstitious mentality and belief about the architectures created in the cave as their God.

Though in the interior it is restricted but people can easily use the limestone for their domestic purposes which are taken from the surroundings of the cave (Jha and Bairagya, 2011). The entrance of the cave (Plate 7) is made well decorated by the Govt. of Andhra Pradesh to attract the visitor's attention. People of Eastern Ghats can earn lot of money from the tourists visited there to enjoy the scenic beauty of the cave.

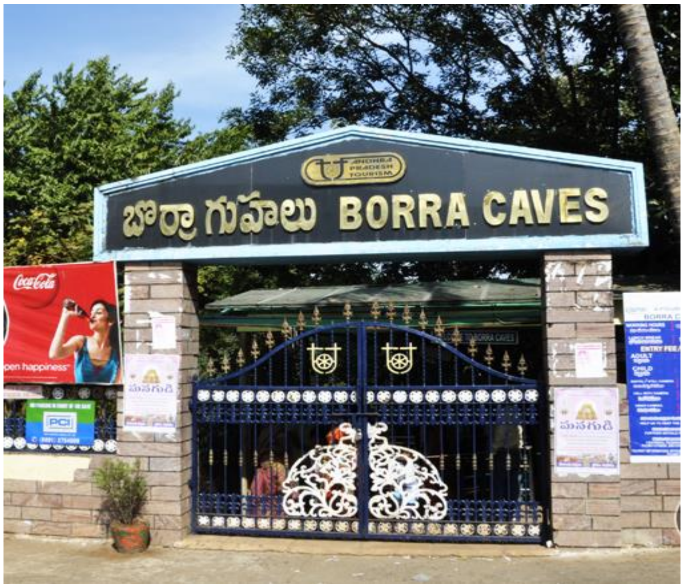

Plate 7. Entrance of the Cave

Conclusion

The Borra Cave is one of the most attractive tourist destinations of India as well as the world for its beautiful natural phenomenon and its superstitious characteristics. A great deal of scientific interest has been generated by the cave. Mineralogists and gem collectors know the Borra cave contain many large and perfect crystals. Paleontologists have found fossils in the inner cave which shed light on the history of man. Geologists have attempted to answer several theoretical and practical questions posed by the Borra cave. The geographers are trying to solve the problems by describing the cave perfectly and analyzing the reason behind its formation.

Owing to presence of lot of local people surrounding the cave to make their economic activities and regular gathering of the tourists inside the cave disturbing the ecosystem and biodiversity of the cave environment.

The one million year old stalactite and stalagmite formations at the Borra Cave is a truly breathtaking sight to behold for the tourists but the Govt. has to take necessary steps to control the noise, disturbance and pollution surrounding the cave. The discussion about the Borra cave will help the geographer to go forward in future because of its detailed description, analysis and to unveil the mystery of the cave.

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