

# Speleothems as Paleoclimate and Paleomonsoon Indicator : Evidences from NW Himalaya and the Shillong Plateau, NE India

V. C. TEWARI

Wadia Institute of Himalayan Geology, Dehradun- 248001, Uttarakhand

Email : vtewari@wihg.res.in

**Abstract :** Himalayan speleothems may provide important record of Holocene palaeoclimate and palaeomonsoon since they are not subjected to diagenesis, erosion and terrestrial deposits. Miocene to Holocene palaeoclimatic, paleoceanographic, palaeomonsoonal studies from the tropical and monsoonal regions of Indian ocean and subcontinent and SE Asia has been attempted in recent years (Anil Gupta, 2010, 2011; Fleitmann et al., 2003; Sinha et al., 2005; Yadav, 2005; Tewari, 2008, 2009). Carbon and oxygen isotopic variations in speleothems especially stalagmite growth laminae is used for interpreting the amount of rainfall (Tewari, 2011). In the present paper some very important speleothem deposits have been studied from the Kumaon, Garhwal and Himalaya in the NW and Shillong Plateau in the NE region. Salient features of the stalactites, stalagmites and flowstones are described in detail from these caves. These caves are located in the Sahastradhar and Tapkeshwar areas of Dehradun, Prakateshwar cave in Uttarkashi, Chulerasim near Chaukhutia and Patalbhubaneshwar near Gangolihat town of Almora and Pithoragarh districts of the Kumaon Himalaya. In the NE, the caves have been studied from Mawsmi, Mawmluh and Mustos areas in the East Khasi Hills, Shillong Plateau, Meghalaya. The samples were collected from caves for the sedimentological microfacies of the speleothems, carbon and oxygen isotopic ratios of the stalactites and stalagmites for palaeoenvironmental and palaeoclimatic interpretations. All these caves lie in the high monsoonal region therefore, it is quite significant to study the strength of Indian Summer Monsoon (ISM) and decadal scale seasonal variations. The high resolution  $^{230}\text{Th}$  dating of stalagmites from these unexplored caves will help in calculating the amount of rainfall due to South West ISM and their exact timing of formation and decadal scale monsoonal variation. It is also attempted to establish a relationship between the climate- monsoon and tectonics.

**Keywords :** Speleothems, Himalaya, Meghalaya, Intertropical Convergence Zone (ITCZ) paleoclimate, Indian Summer Monsoon, Isotopes.

## INTRODUCTION

Speleothems potentially contain the most complete record of past climate change and monsoon in the Himalayan caves from NW to NE (Tewari, 2011). The oxygen and carbon isotopic analysis of the speleothems document intensity of Indian Summer Monsoon rainfall. The U- $^{235}\text{Th}$  dating along speleothem growth axis from Cave deposits or Speleothems are natural archives of the paleoclimate record and abundantly found in the Himalaya from NW to NE India, where calcium carbonate is precipitated as flowstones, stalactites and stalagmites. Recently, much attention has been focused on cave calcites (speleothems) as archives of climatic and paleoenvironmental changes in terrestrial environments. Factors contributing to make

speleothems valuable paleoenvironmental indicators include: (1) their high preservation potential shielded from Earth-surface erosional processes; (2) their crystalline structure, frequently composed of coarsely crystalline inorganic calcite ( $\text{CaCO}_3$ ) that records geochemical signatures of global and regional events transferred through atmospheric processes; and (3) the resistance of speleothems to post-depositional recrystallisation and diagenesis.

The Sahastradhara, Prakateshwar, Chulerasim and Patal Bhubaneshwar caves of the Uttarakhand were studied for paleoclimate change. However the sedimentological, C and O isotopic ratios and geochemical results obtained from these caves in the NW and similar

investigations from the Mawmluh and Mawsmi caves from Meghalya are presented in this paper. In Dehradun valley, the oxygen isotopic ratios range from 21.02 ‰ to 25.22 ‰ (SMOW) and carbon isotopic ratios range from -4.34 ‰ to -6.42 ‰ (PDB) in the speleothems. The variation of  $\delta^{18}O$  in speleothems is related to the precipitation amount during the monsoon season. It is highlighted here that during the month of September 2010 when the field work was carried out, there was heavy rainfall in the whole Uttarakhand region and in Dehradun city itself the record of rainfall of last forty years was broken. It is widely recognized that caves can also host a wide spectrum of fascinating life forms, starting from biofilms harbouring different types of micro-organisms to different types of cave-dwelling animals. Cave geomicrobiology deals specifically with the micro-organisms other life forms and their interactions with minerals and provide us with information about past geomicrobiological interactions (Baskar *et al.*, 2011). Laboratory experiments have shown that bacterial species isolated from caves are able to precipitate carbonates under controlled conditions (Tewari, 2008, 2009, 2011 in Baskar *et al.* 2011).

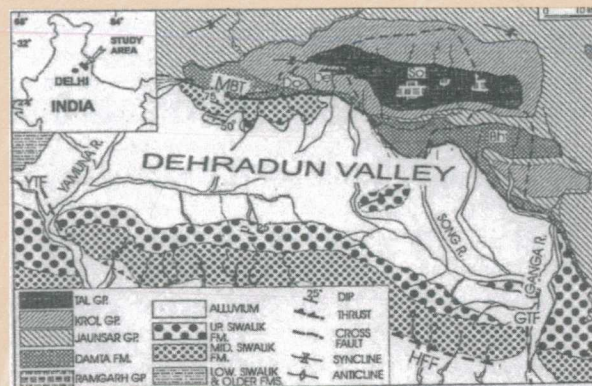
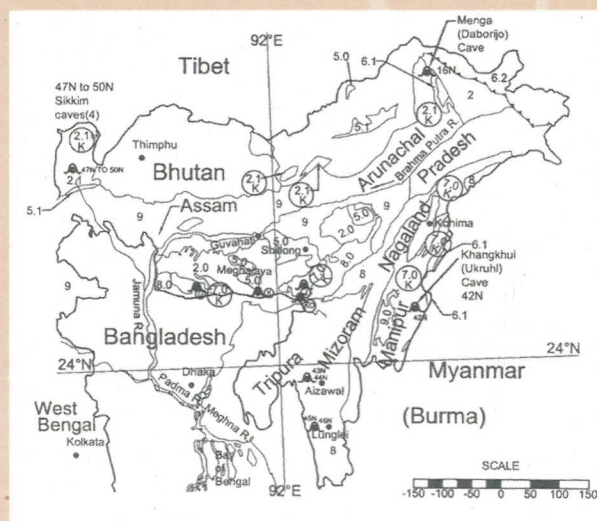
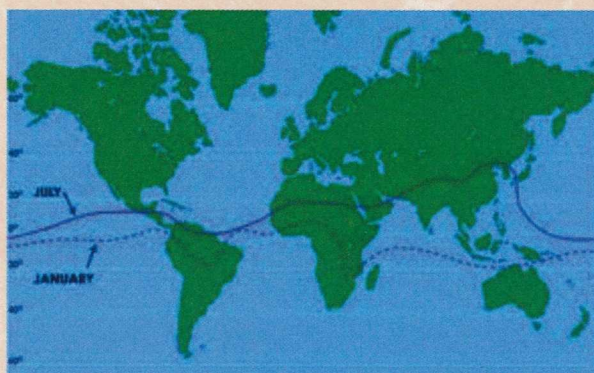


Fig 1. Locations of the Speleothems from NE Himalaya Shillong Plateau and Dehradun valley (Singh *et al.*, 2001).

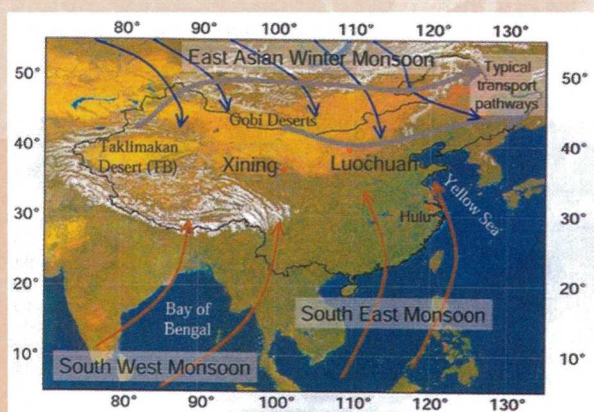
Deshmukh (1994) has reviewed the occurrence of caves in the Indian sub-continent. These caves were investigated in different ways, ranging from traditional to a molecular microbiological point of view and, geochemical, mineralogical, stable isotope studies to explore the extent of microbial processes and their impact in precipitating carbonate deposits in these caves. The recognition of the importance of speleothems as archives for paleoenvironmental changes has increased over the last three decades (Hendy, 1971). The mechanisms of speleothem deposition have been proven to be sensitive to external, often climatic driven processes that respond to annual-decadal short as well as to long-term changes (Wang *et al.*, 2004). Speleothems can therefore be regarded as valuable archives of climatic conditions on the continents. Compared to other continental climate proxy recorders from lake sediments and peat cores, speleothems offer several advantages. These include worldwide distribution of caves containing speleothems, high precision uranium-series dating of speleothems and highly resolved time series data, and mostly easier accessibility. Based on this, the speleothem records from caves across Asia have contributed with new knowledge to our current understanding of many of the factors that control inter-annual to millennial scale variability in Asian monsoon precipitation



(Wang *et al.*, 2008; Sinha *et al.*, 2005; Fleitmann *et al.*, 2007; Overpeck and Cole, 2007) and provided important constraints for climate modeling scenarios. Indian Summer Monsoon (ISM) supplies 80% of Southeast Asia's annual precipitation and is vital to sustaining the region's agriculture, which supports a quarter of the world's population. Abrupt shifts in the Indian Summer Monsoon (ISM) could accompany abrupt changes in global climate in the future. The Oxygen isotope ratios of stalagmite calcite to primarily reflect variation in the amount of rainfall with more negative  $\delta^{18}O$  reflecting higher monsoonal rainfall and economic importance to billions of people (Burns *et al.* 1998; Fleitmann *et al.* 2003, 2007; Gupta 2010, 2011; Tewari 2008, 2009, 2011a,b)



a



b

**Fig. 2** a,b Intertropical Convergence Zone (ITCZ, a) and the direction of movement of the South West, South East and East Asian Winter Monsoon over the Himalaya and the Tibetan Plateau (source Wikipedia).

### Speleothems from Kumaon - Garhwal Lesser Himalaya, Uttarakhand

The cave systems at Sahastradhara, are situated in the Dehradun Valley a crescent shaped intermontane valley formed within the Siwalik Formations in Garhwal Himalaya (Fig.1). They are situated on the Krol carbonates and enclosed by the rivers Ganga in the east and Yamuna in the west. The caves are rather small in size (10 m long, 2 m wide), and are well known for their pH neutral springs that are believed to cure various kinds of skin diseases. The word Sahastradhara means the place of the 'thousand-fold spring'. The areas around the caves are frequently visited by people throughout the year, mainly due to the therapeutic value of the springs. However, nobody enters these caves due to their small sizes. The geology of the Dehradun Valley has been extensively studied (Singh *et al.*, 2001, Tewari, 2007).

The speleothems found in these cave systems in Sahastradhara, Dehradun (Tewari, 2008, 2009, 2011) were studied for sedimentology, mineralogy and geochemistry. Calcite was the dominant mineral in the stalactites. Thin section petrography revealed that the stalactites consisted of microcrystalline calcite or micrite that occurred in chains, attributable to mineralized bacterial cells. The microfacies of the Sahastradhara stalactites show radial fibrous calcite. (Tewari, 2008). In addition, laboratory-based culture experiments using bacterial strains (identified by 16S rRNA gene amplification and sequencing as *Bacillus thuringiensis* and *Bacillus pumilis*) isolated from stalactites showed that they are able to form  $CaCO_3$  crystals (Baskar *et al.*, 2011).

### MATERIALS AND METHODS

The Chulerisma and Patalbhubaneswar speleothems are made up of stalactites and stalagmites. The Chulerasim and Patal bhubaneswar caves are situated in the Lesser Himalayan Meso-Neoproterozoic Gangolihat Dolomite Belt. The dolomite is stromatolitic and cherty and was deposited in the tidal flat

(shallow marine) environment (Tewari, 2011). The caves are not well ventilated, narrow and a variety of flowstones, hairy thin stalactites, broad and wide stalagmites have been recorded. The stalactites show wavy laminations of alternating dark and light bands of calcite and the possible presence of bacteria to form calcite precipitation. The microfacies of the stalactites show radial fibrous calcite. Possibly the Mg has triggered the formation of radial fabric. Microbial precipitation of the carbonate is revealed by the presence of microstromatolitic structures and probable cellular microbiota. The culture experiments may demonstrated the role of microbes (PCR) amplification of 16S rRNA genes (16S rDNA) in the stalactite formation (Baskar *et al.*, 2011). Other carbonate mineral present is aragonite formed in fresh water. Various types of light (carbonate) and dark (organic) laminae is related to the microclimatic decadal scale seasonal variations.

The variation of  $\delta^{18}\text{O}$  in stalagmites is generally related to the precipitation amount during the monsoon season. The oxygen isotopic composition of speleothem calcite from tropical and monsoon locations are primarily controlled by the  $\delta^{18}\text{O}$  value of precipitation.  $\delta^{18}\text{O}$  values of regional precipitation and that changes in calcite  $\delta^{18}\text{O}$  over time primarily reflect changes in the amount of monsoonal precipitation. Cave calcite also contains information about the isotopic composition of meteoric precipitation, is widespread and can be dated with  $^{230}\text{Th}$ . Thus, a detailed high resolution  $\text{O}$  isotope speleothem data from the Himalaya is currently being produced which may give well dated record of palaeomonsoon history. Fleitmann *et al.* (2003) and Tewari (2009, 2011) have interpreted that the western part of (ISM) in Oman and Yemen, the oxygen isotope ratios of stalagmite calcite primarily show variations in the amount of rainfall with more negative  $\delta^{18}\text{O}$  indicating higher monsoon rainfall. In the earlier study by the author (Tewari, 2009, 2010) also, negative  $\delta^{18}\text{O}$

values have been recorded from the Himalayan speleothems (Brahmakhal and Sahastradhara caves). The Brahmakhal (Prakateswar) caves were discovered in 1978 and are situated near the village Mehar Gaon in Uttarkashi district of the Garhwal Himalaya ( $30^{\circ}23'145''\text{N}$ ;  $78^{\circ}07'743''\text{E}$ ). Stalactites and stalagmites are well developed in the cave. (Tewari, 2008, 2009). The thin sections of the stalactites have been studied for mineralogical and microfacies analysis. Radiating fibrous calcite and microlamination of calcite and organic-rich microbial laminae have been recorded in the Prakteshwar speleothems (Tewari, 2008, 2009, Tewari 2011 in Baskar *et al.* 2011).

### **Speleothems from Shillong Plateau, East Khasi Hills, Meghalaya**

Meghalaya is one of the north-eastern states of India and the state harbours more than 1,000 caves, a few of them form some of the longest caves in the Indian subcontinent (Fig. 1). 'Meghalaya,' means 'the abode of clouds,' derived from the Sanskrit words - 'megh' meaning cloud and 'alaya' meaning home. Geomicrobiological studies have so far been carried out only on two of the more than 1000 cave systems in Meghalaya: the Mawsmi ( $25^{\circ}07'\text{N}$ ,  $91^{\circ}21'\text{E}$ ) and the Krem Phyllut caves ( $25^{\circ}41'\text{N}$ ,  $92^{\circ}09'\text{E}$ ) are located on the East Khasi Hills (Figs. 3a,b,c,d). The Khasi Hills is an uplifted Precambrian crystalline complex and forms the northeastern extension of the Indian Peninsular Shield. It is an E-W trending oblong horst block elevated about 600–1,800 m above the Bangladesh plains in south.). The state has huge deposits of limestone and abundant rainfall, which is one of the main reasons for formation of these magnificent Karst caves. The important limestone deposits in the East Khasi Hills are in the Mawmluh-Mawsmi Hills of Paleocene Lakadong Limestone deposited after the Cretaceous - Paleogene (K/Pg) boundary in the Meghalaya Plateau (Tewari *et al.*, 2010, a, b). The cave (Figure 3a, b) lies south of the wettest place in the world - Cherrapunji town now renamed as Sohra in local language.

These caves are not so easily accessible for the public since they are situated in a hilly, uninhabited area. The Mawsmi caves are located in a thick forested area and are quite small (160 m long, 15 m high, 4–10 m wide), but the inner parts are large enough to facilitate movement in the passage ways. The main entry to these caves is located close to the Mawsmi village and the entry is a fairly narrow (1.8 m) vertical opening. The cave is totally aphotic and has many stalagmites and stalactites. The average annual temperature of the inner cave is ~15–19°C. The stalactites range in sizes from 7–10 cm length and 8–15 cm diameter (small), to 50–150 cm length and 50–100 cm diameter (large). The Krem Phyllut caves have a large fossil passage way. This cave is relatively large (total length of 1003 m, width 4.5 m, height 15 m) and has three entrances (approximately of 2 m height, 2.5 m width). The deep aphotic inner cave wall had an average annual temperature of ~15–17°C. Two springs run about 500 m through the cave. The length and diameter of the stalactites range from 6–7 cm in length and 25–30 cm in diameter (small) to 30–40 cm in length and 50 cm in diameter (large). The columns are 40–45 cm long and the diameter of the upper end is 40 cm and that of the lower end is 60 cm. The speleothems are larger at the entrance and smaller towards the interior. The main cavern extends to about 50–60 m and narrows to a much smaller tunnel wherein gypsum deposits are found. Baskar et al (2011) reported the possible influence of microorganisms on the speleothem in Meghalaya. The spring waters have a pH of 7.4–7.8 and the speleothems have a TOC content of ~0.37–1.98 wt%. The water (spring, pool and dripping) contained concentrations of 37 ppb Sr, 1.5–2.6 ppb Si, 3–12 ppb Cr, 4–5 ppb Ba, 1–4 ppb Cu, 3–28 ppb Zn, 2.3–5.8 ppb Mg and in addition to calcium the speleothems contained 0.12–1.69 Fe<sub>2</sub>O<sub>3</sub>, 0.31–0.91% MgO, 0.002–0.131% Na<sub>2</sub>O, 0–3.24% Al<sub>2</sub>O<sub>3</sub> and 46–501 ppm Sr. In the Chulerasim stalagmite, Kumaon Lesser

Himalaya CaO varies from 52.85–54.88 %; MgO from 1.02 – 2.12%; Na<sub>2</sub>O from 0.004– 0.006% ; Al<sub>2</sub>O<sub>3</sub> from 0.01– 0.09%; SiO<sub>2</sub> from 0.10– 1.54%; P<sub>2</sub>O<sub>5</sub> from 0.011– 0.017%; K<sub>2</sub>O remains 0.01% ; TiO<sub>2</sub> from 0.001– 0.006% ; MnO from 0.001 – 0.003% and Fe<sub>2</sub>O<sub>3</sub> from 0.01 – 0.07%.

Recently, the cellular structures and diatoms of microbiological origin have been found in the petrographic thin sections from the Sahastradhara caves and further confirmed in the Scanning Electron Microscopy. The microbial fossils observed are semi circular filamentous structure of cyanobacteria and a well preserved spheroidal cell. Combined SEM and Energy Dispersive X- ray Microanalysis (EDX) of these microbes have been done. The predominance of Ca is recorded in the microbes in EDX analysis, however Si, K, S, Mg and Cl is also present in minor amount in some of the microbes such as diatoms etc. Microscopic studies of the stalactites and stalagmites from the Sahastradhara caves show normal, wavy as well as crenulated laminations of precipitation. The microfacies of the speleothems show micrite, sparite sparry dolomite, radial fabric fibrous calcite. Possibly the Mg has triggered the formation of radial fabric. Various types of light (carbonate) and dark (organic) laminae is related to the microclimatic decadal scale seasonal variations. The thickness of the dark and light laminae is variable. The interlaminar spaces are highly recrystallised due to intense diagenetic process. More than 200  $\mu$  dolorhombs have been found in the diagenetic change.

The petrographic identification of the Mg calcite is further confirmed by the XRD peaks of calcite. The SEM- EDX combined study of the filamentous and spheroidal microbes and diatoms have shown the presence of mainly Ca in the cells and suggest microbial origin.



Phyllut and Mawmluh Caves, East Khasi Hill, Meghalaya

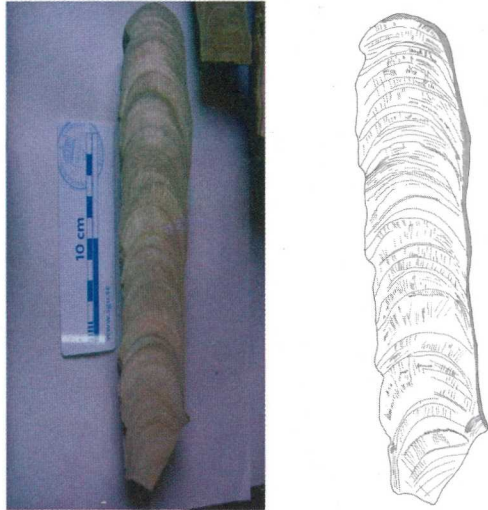


Fig.3. a, b, c, d. (Speleothems from Phyllut and Mawsmai caves, polished slab and sketch of laminae).

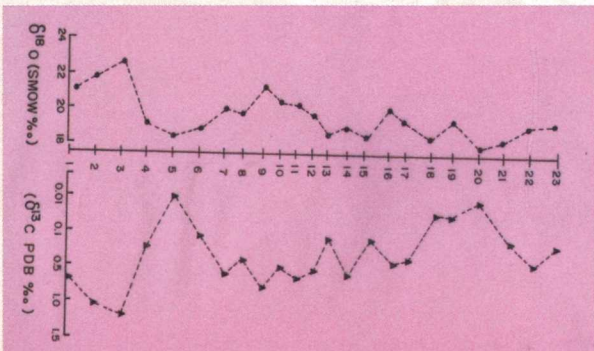


Fig.4. Carbon and oxygen isotope variation in the speleothem from the Meghalaya

### Paleomonsoon , Stable Isotope , Climate and Tectonics Relationship

Studies on Indian speleothems to estimate the past monsoon and climate is also taking momentum, and very interesting results on the paleomonsoon variability preserved in stalagmites have been published (Yadava et al., 2004; Yadava and Ramesh, 2005; Ramesh, 2001; Sinha et al., 2005; Tewari 2008, 2009, 2011a,b). Speleothems may also provide archives of past precipitation since the oxygen isotopic ratio of stalagmite calcite is controlled by  $\delta^{18}O$  values of precipitation. Thus, Yadava et al. (2004), Yadava and Ramesh (2005) and Ramesh (2001) reconstructed the monsoon precipitation from  $\delta^{18}O$  of cave stalagmite from Gupteshwar cave, Orissa in east India, back to 3400 years B.P. Similarly, Sinha *et al.* (2005) studied the Timta cave in the Kumaon Himalaya, and the oxygen isotope ratio ranged from  $-5.2$  to  $-8.4$  per mil for this period. The difference of about  $-3.2$  per mil was interpreted to reflect the varying strength of the Indian Summer Monsoon system. More recently, Tewari (2008, 2009) studied the carbon and oxygen isotopic signatures of a number of caves from the Garhwal Lesser Himalaya, north India. The  $\delta^{13}C(PDB)$  of the Sahastradhara stalactites range from  $-2.47$  to  $-6.06$  per mil and  $\delta^{18}O$  from  $22.99$  to  $26.21$  per mil. In Brahmakhal cave the  $\delta^{13}C(PDB)$  vary from  $-5.34$  to  $-7.65$  per mil and  $\delta^{18}O$  vary from  $20.67\%$  to  $22.84\%$ . The  $\delta^{13}C(PDB)$  value of Pratapnagar modern stalactite calcite varies from  $-4.85$  to  $-9.23$  per mil and the  $\delta^{18}O$  range from  $19.50$  to  $21.57$  per mil. In Chulerasim speleothem the  $\delta^{13}C(PDB)$  varies from  $-1.83$  ‰ PDB to  $-7.74$  ‰ PDB and  $\delta^{18}O(VPDB)$  varies from  $-3.06$  ‰ (VPDB) to  $-6.33$  ‰ (VPDB). The variation in oxygen and carbon isotopes in the speleothem of the Mawsmai cave, South Shillong Plateau (Meghalaya) is generated for the first time and this relationship is depicted in the figures 4a, and 4b. The  $\delta^{18}O(SMOW)$  shows depletion in the isotopic values, hence increased precipitation in the area.

As discussed above, variation of  $\delta^{18}O$  in

stalagmites is related to the  $\delta^{18}O$  values in the precipitation and the amount of precipitation during the monsoon season.  $\delta^{18}O$  values of regional precipitation and the changes in calcite  $\delta^{18}O$  over time reflect changes in monsoonal precipitation. Study of modern cave drip waters and stalagmites demonstrates that the stalagmites were deposited in or very near to isotopic equilibrium. The  $\delta^{18}O$  isotope data of drip water from Sahastradhara cave in Dehradun during the monsoon season (August and September, 2007- 2011)

varies from -4.58 ‰ ( VPDB ) to -5.14‰ ( VPDB ).

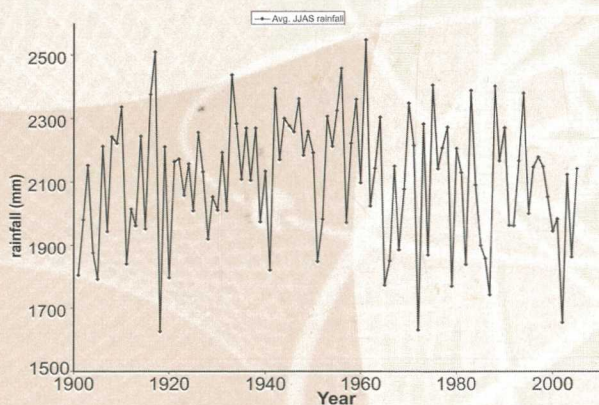
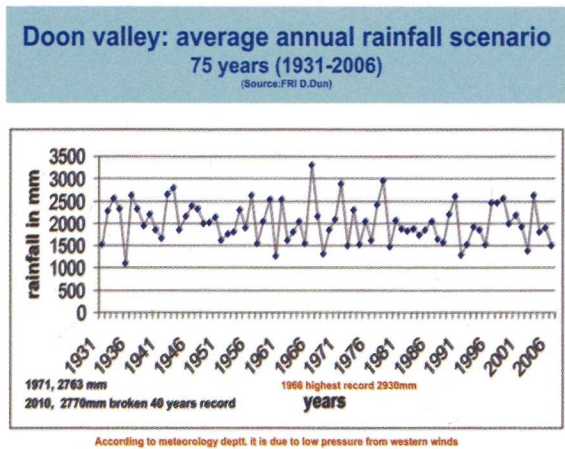


Fig. 5 a,b. Average annual rainfall scenario (75 years) of Doon valley (a,left) and India (b,right)

Fleitmann *et al.* (2003), and the references therein) have interpreted that the western part of Indian Summer Monsoon in

Oman and Yemen and showed variations in the amount of rainfall with more negative  $\delta^{18}O$  values indicating higher precipitation. Negative  $\delta^{18}O$  values have also been recorded in the Sahastradhara , Brahmakhal and Chulerasim caves in the Uttarakhand Himalaya and Mawsmai cave in the Meghalaya, NE India. Cave calcite also contains information about the isotopic composition of meteoric water from which calcite is precipitated and dated calcite from speleothem with U/Th disequilibrium series method. Thus, detailed high resolution O isotope speleothem data from other cave systems in the NW and NE Himalaya may yield interesting insights into the record of palaeomonsoon history. The climate over the Arabian sea , Indian subcontinent and East Asia is known to largely depend on the Indian Summer Monsoon ( SW Monsoon), SE Monsoon, East Asian Winter Monsoon and Intertropical Convergence Zone (ITCZ , Fig. 2a and 2b ). High resolution climate and monsoonal records are preserved in rapidly depositing continental margin sediments. The average annual rainfall scenario of the Dehradun valley and India in general has been shown in Fig. 5a and b (source FRI, Dehradun and IMD, New Delhi).

### DISCUSSIONS AND CONCLUSIONS

Cave deposits or Speleothems are natural archives of the paleoclimate record and abundantly found in the Himalaya from NW to NE India, where calcium carbonate is precipitated as flowstones stalactites and stalagmites. Himalayan speleothems may provide important record of palaeoclimate and palaeomonsoon since they are not subjected to diagenesis, erosion and terrestrial deposits. Miocene to Holocene palaeoclimatic, paleoceanographic, palaeomonsoonal studies from the tropical and monsoonal regions of Indian ocean and subcontinent and SE Asia has been attempted in recent years Carbon and oxygen isotopic variations in speleothems especially stalagmite growth laminae is used for interpreting the amount of rain fall. Caves from the Shillong Plateau, Meghalaya have been

studied for the sedimentological microfacies of the speleothems, carbon and oxygen isotopic ratios of the stalactites and stalagmites for palaeoenvironmental and palaeoclimatic interpretations. All these caves lie in the high monsoonal region therefore, it is quite significant to study the strength of Indian Summer Monsoon (ISM) and decadal scale seasonal variations (Gupta 2010, 2011). The Mawsmai, Mawmluh and Mastos cave system lies in the Sohra (Cherrapunji) area of the Shillong Plateau, Meghalaya where highest annual rainfall is 11931.7 mm. It is the wettest place on planet earth. The high resolution  $^{230}\text{Th}$  dating of stalagmites from these unexplored caves will help in calculating the amount of rainfall due to South west ISM and their exact timing of formation and decadal scale monsoonal variation. Speleothems are least altered deposits and very reliable to study the Monsoon pattern of the past. The long term rainfall and precipitation variability over the Himalaya is not well established. Negative oxygen isotope values have been recorded for speleothems from the Meghalaya caves and is consistent with the data available from other caves in the Uttarakhand region indicating higher monsoon rainfall.

Microscopic studies of the stalactites and stalagmites show wavy laminations of alternating dark and light bands of calcite and the possible presence of bacteria to form calcite precipitation. The microfacies of the speleothems show radial fibrous calcite. Possibly the Mg has triggered the formation of radial fabric. Other carbonate mineral present is aragonite formed in fresh water. Various types of light (carbonate) and dark (organic) laminae is related to the microclimatic decadal scale seasonal variations. Cathodoluminescence study of the speleothems show bright luminescence. Geochemical and

carbon and oxygen isotopic variation in these speleothems is discussed and interpreted. The variation of  $\delta^{18}\text{O}$  in stalagmites is generally related to the precipitation amount during the monsoon season. The oxygen isotopic composition of speleothem calcite from tropical and monsoon locations are primarily controlled by the  $\delta^{18}\text{O}$  value of precipitation.  $\delta^{18}\text{O}$  values of regional precipitation and that changes in calcite  $\delta^{18}\text{O}$  over time primarily reflect changes in the amount of monsoonal precipitation. Cave calcite also contains information about the isotopic composition of meteoric precipitation, is widespread and can be dated with  $^{230}\text{Th}$ . Thus, a detailed high resolution O isotope speleothem data from the Himalaya is currently being produced which may give well dated record of palaeomonsoon history. The intensification of the Indian monsoon may spin the earth's tectonic plates. There could be a relationship between the tectonically disturbed speleothems ( Fig. 3a ), movement of the Indian Plate over the last ten million years and the intensification of the Indian Summer Monsoon (ISM). The climate change must have effected the monsoon which increased the rainfall in the Meghalaya (Cherrapunji/Sohra) as per the annual rate of increase in rainfall. This might have enhanced the speed of the Indian Plate by one cm per year. Therefore the detailed study of the cave deposits of the NE region has direct impact on the climate change, monsoon variability and possibly earthquakes.

Acknowledgements : Professor A. N. Sial,, NEG- LABISE, University of Pernambuco , Recife , Brazil is thanked for analyzing the speleothems for C and O isotopes in his laboratory. He is thankful to Professor Anil. K. Gupta, Director, Wadia Institute of Himalayan Geology, Dehradun for encouraging the speleothem research and providing the facilities. The anonymous reviewers are thanked for their critical comments and valuable suggestions.

## References

BASKAR, S., BASKAR, R., TEWARI, V.C., THORSETH, I.H., LISE OVRIAS, LEE, N.M., and RAUTH J. (2011) Cave geomicrobiology in India: Status and Prospects. In: *Stromatolites* ;

*Interaction of Microbes with Sediments*, Tewari, V.C. and Seckbach, J (editors), Springer Science + Business Media B.V.2011, Heidelberg, pp.541-570.



- BURNS, S.J., MATTER, A., FRANK, N., MANGINI, A. (1998) Speleothem -based paleoclimate record from northern Oman. *Geol. Soc. of America*, v. 26(6), pp.499-502.
- DESHMUKH, M. (1994) Influence of geology on the localization of ancient caves. *Jour. Geol. Soc. India*, v. 44, pp. 213-217.
- FLEITMANN, D., BURNS, S.J., MANGINI, A., MUDELSEEE, M., KRAMERS, J., VILLA, I., NEFF, U., AL-SUBBARY, A.A., BUETTNER, A., HIPPLER, D. and MATTER, A. (2007) Holocene ITCZ and Indian monsoon dynamics recorded in stalagmites from Oman and Yemen (Socotra). *Quat. Sci. Rev.* v.26, pp. 170-188.
- FLEITMANN, D., BURNS, S.J., MANGINI, A., MUDELSEEE, M., KRAMERS, J., VILLA, I., NEFF, U., AL-SUBBARY, A.A., BUETTNER, A., HIPPLER, D. and MATTER, A. (2003). Holocene forcing of the Indian monsoon recorded in a stalagmite from Southern Oman. *Science*, 300, pp.1737-1739.
- GUPTA, ANIL. K. (2010) Evolution of the Indian monsoon since Late Miocene intensification - marine and land proxy records. *Jour. Paleont. Soc. India*, v.55(1), pp.1-9.
- GUPTA, ANIL. K. (2011) Paleoceanographic evolution of the Indian Ocean during the Neogene. Fourth Professor P.B. Varma Memorial Lecture, Department of Geology, Lucknow University, April 7th 2011, pp. 1-16.
- HENDY, C.H. (1971) The isotopic geochemistry of speleothems - 1. The calculation of the effects of different modes of formation on the isotopic compositions of speleothems and their applicability as paleoclimatic indicators. *Geochimica et Cosmochim. Acta*, v.35, pp.801 - 824
- OVERPECK, J.T. and COLE, J.E. (2007) Climate change: Lessons from a distant monsoon. *Nature*, v. 445, pp.270-271.
- RAMESH, R. (2001) High resolution Holocene monsoon records from different proxies: An assessment of their consistency. *Special Section: Climate, Monsoon and India's Water. Current Science*, v. 81, (11), pp. 1432-1436.
- SINGH, A.K., PRAKASH, B., MOHINDRA, R., THOMAS, J.V. and SINGHVI, A.K. (2001). Quaternary alluvial fan sedimentation in the Dehradun Valley piggyback basin, NW Himalaya: tectonic and paleoclimatic implications. *Basin Res.*, v.13, pp. 449-471.
- SINHA, A., CANNARIATO, K.G., STOTT, L.D., CHENG, H., EDWARDS, R.L., YADAVA, M.G.; RAMESH, R. and SINGH, I.B. (2005) Variability of southwest Indian summer monsoon precipitation during Bolling - Allerod. *Geol. Soc. Am.*, 33, v.10, pp.813-816.
- TEWARI, V.C. (2007) The rise and decline of Ediacaran biota: Paleobiological and stable isotopic evidence from the NW and NE Lesser Himalaya, India, Geological Society of London, Special Publication, In: (eds.) Vickers Rich, P and Komarower, P, v.286, pp.77- 101.
- TEWARI, V.C. (2008) Speleothems from the Himalaya and the Monsoon: A preliminary study, *Earth Science India*, v. 1, IV, pp.. 231-142.
- TEWARI, V.C. (2009) Speleothems from the Himalaya, paleoclimate and monsoon, In: *Advances in Earth Science*, S.K. Tandon and A.R. Bhattacharyya (ed.), Satish Serial Publishing House, Delhi, India. pp.91-99.
- TEWARI, V.C. (2011a) Speleothems from Uttarakhand and Meghalaya indicating Holocene Monsoon and climate. *Jour. Indian Geol. Cong.*, v. 3 (1), pp.87- 104.
- TEWARI, V.C. (2011b) Speleothems and monsoon : continental record of climate change from the Himalaya. In : *International Conference on Indian Monsoon and Himalayan Geodynamics (IMHG-2011)*, Wadia Institute of Himalayan Geology, Dehradun, November 2-5. 2011. p.96(ab).
- TEWARI, V.C., LOKHO, K., KUMAR, K. and SIDDAIAH, N.S. (2010a) Late Cretaceous - Paleocene basin architecture and evolution of the Shillong shelf sedimentation, Meghalaya, Northeast India. *Jour. Indian Geol. Congr.*, v.2 (2), pp.61-73.
- TEWARI, V.C., KUMAR, K., LOKHO, K., and SIDDAIAH, N.S. (2010b) Lakadong Limestone : Paleocene - Eocene boundary carbonate sedimentation in Meghalaya, northeastern India. *Curr. Sci.*, v. 98 (1), pp.88-95.
- WANG, X., AULER, A.S., EDWARDS, R.L., CHENG, H., CRISTALLI, P.S., SMART, P.L., RICHARDS, D.A., SHEN, C.C. (2004) Wet periods in northeastern Brazil over the past 210 kyr linked to distant climate anomalies. *Nature*, v. 432, 740-743, doi: 10.1038/nature 03067.
- WANG, Y.J., CHENG, H., EDWARDS, R.L., KONG, X.G., SHAO, X., CHEN, S., WU, J.Y., JIANG, X.Y., WANG, X.F. and AN, Z. S. (2008) Millennial- and orbital-scale changes in the East Asian monsoon over the past 224,000 years, *Nature*, v.451, pp.1090-1093.
- YADAVA, M.G. and RAMESH, R. (2005) Monsoon reconstruction from radiocarbon dated tropical Indian speleothems. *The Holocene*, v. 15 (1), pp. 48-59.
- YADAVA, M.G.; RAMESH, R. and PANT, G.B. (2004) Past monsoon rainfall variations in peninsular India recorded in a 331 year old speleothem. *Holocene*, v.14, pp.517- 524.