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# Cave 'Krem Mawmluh' of Meghalaya plateau – The base of the 'Meghalayan Age' and '4.2 ka BP Event' in Holocene (Anthropocene)

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## ABSTRACT

Our land, the Meghalaya plateau, has been attracting enormous attention of worldwide academia since the ratification of subdivisions of the Holocene Epoch into three Ages, *viz.*, the Greenlandian, the Northgrippian and the Meghalayan, which correspond to the Early, Middle and Late Holocene, respectively, by the International Union of Geological Sciences (IUGS) in July, 2018. The evidences for determining the stratigraphic boundary of the Meghalayan Age were fetched from the cave 'Krem Mawmluh' near Cherrapunji in the State of Meghalaya, India. Thus, we are now living in the Phanerozoic Eon, Cenozoic Era, Quaternary Period, Holocene Epoch, and 'Meghalayan Age' in 'icehouse climate state' of the Earth. The Meghalayan Age began 4,200 years before present (*i.e.*, before 1st January 1950) or 4,250 years before 2000 AD (*i.e.*, b2k). It is concisely popular as '4.2 ka BP Event'. This event of abrupt and large scale climate change is attributed with the fall of four major ancient civilizations. The Meghalayan Age marks a period of intense human-environment interactions and their impact on the Earth's ecosystems, ecology, biodiversity, climate and weather patterns, and constitutes an important stage in informally termed epoch, the 'Anthropocene'.

**Keywords**: Meghalayan Age, 4.2 ka BP Event, Holocene, Anthropocene, Cave Mawmluh, Meghalaya.

## INTRODUCTION

In a simplified view, the history of the Earth on Geological Time Scale (GTS) can be stated briefly into: i) Precambrian SuperEon, and ii) Phanerozoic Eon (Fig. 1). The Precambrian is typically divided into three Eons: Hadean, Archaean and Proterozoic. Each of these Eons is further subdivided into Era. Similarly, the Phanerozoic Eon has three divisions: Paleozoic Era (dominance of Fishes), Mesozoic Era (dominance of Dinosaurs) and Cenozoic Era (dominance of Mammals). The term Phanerozoic refers to the time since the beginning of life or appearance of biota (*phanero*=plants, and *zoic*=animals) on the Earth, *i.e.*, nearly 543 Ma or mya (million years ago). Each of these Eras is subdivided into Periods. Each Period is subdivided into Ages. Currently, we are living in the Phanerozoic Eon, Cenozoic Era, Quaternary Period, Holocene Epoch. Just about two years ago, the Holocene Epoch was subdivided into three Ages and the last of these, the 'Meghalayan Age' is continuing since 4,200 years BP (before present, *i.e.*, 1st January, 1950). The purpose of this commentary is to highlight this important development in Geology and Stratigraphy for the benefit of the biologists, ecologists, environmentalists and anthropologists, especially in Northeast India.

## THE CLIMATE OF THE EARTH

Historically, the climate of the Earth has been alternating between two states, namely, the 'Greenhouse Earth' and the 'Icehouse Earth' (Luhr 2007). These states last for millions of years, but the greenhouse state has dominated in about 85% of the time of Earth's history (Fig. 2). Currently, the Earth is in an icehouse state, which started 34 Ma at the Eocene-Oligocene boundary and it is the fifth ice age, also known as Late Cenozoic Ice Age (Montanez 2006). The other four (from older to newer ones) are: Huronian Glaciation, Cryogenian, Andean-Saharan Glaciation and Late Paleozoic Ice Age. The periods of greenhouse and icehouse have shaped the evolution of life on the Earth. An ice age is marked by 'glacial' and 'interglacial' periods which are

| S'Eon | Eon | Era | Period | Epoch | Age | Picks |
|---|---|---|---|---|---|---|
| Phanerozoic | | Cenozoic | Quaternary | Holocene | Meghalayan | 0.0042 |
| | | | | | Northgrippian | 0.0082 |
| | | | | | Greenlandian | 0.0117 |
| | | | | Pleistocene | 4 Ages | 2.58 |
| | | | Tertiary – Neogene | Pliocene | 2 Ages | 5.333 |
| | | | | Miocene | 6 Ages | 23.03 |
| | | | Tertiary – Paleogene | Oligocene | 2 Ages | 33.9 |
| | | | | Eocene | 4 Ages | 56.0 |
| | | | | Paleocene | 3 Ages | 66.0 |
| | | Mesozoic | Cretaceous | 2 | 6+6 | 145 |
| | | | Jurassic | 3 | 3+4+4 | 201.3 |
| | | | Triassic | 3 | 3+2+2 | 251.9 |
| | | Paleozoic | Permian | 3 | 2+3+4 | 298.9 |
| | | | Carboniferous | 2 | 4+3 | 358.9 |
| | | | Devonian | 3 | 2+2+3 | 419.2 |
| | | | Silurian | 4 | 0+2+2+3 | 443.8 |
| | | | Ordovician | 3 | 3+2+2 | 485.4 |
| | | | Cambrian | 4 | 3+3+4 | 541 |
| Precambrian | Prote-rozoic | Neo-<br>Meso-<br>Paleo- | 3<br>3<br>4 | | | 2500 |
| | Archa-ean | Neo-<br>Meso-<br>Paleo-<br>Eo- | | | | 4000 |
| | Had-ean | Neo-<br>Meso-<br>Paleo-<br>Eo- | | | | 4600 |

Figure 1. Geological Time Scale (GTS) in million years ago (Ma) showing newly recognized subdivisions of Holocene Epoch into three Ages (green colour). White cells show the number of further subdivisions, whereas grey cells have no further subdivisions. This curtailed depiction is redrawn from The Geological Society of America's GTS V.5.0 (Walker et al., 2018) with addition of three Ages in Holocene Epoch (green colour).

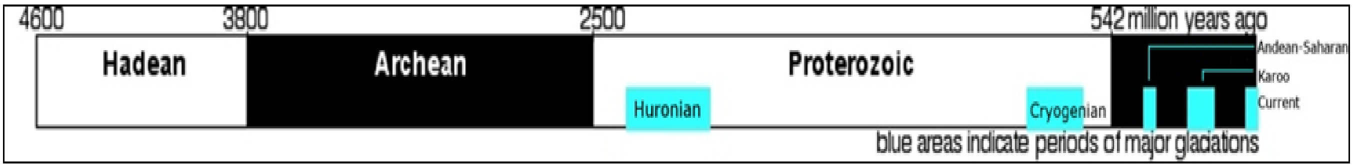


Figure 2. Timeline of five major glaciations on the Earth shown in cyan colour with approximation of their length. From left to right: 1. Huronian (2.4 billion to 2.1 billion years ago), 2. Cryogenian (720 to 635 million years ago), 3. Andean-Saharan (450 to 420 million years ago), 4. Late Paleozoic (360 to 260 million years ago), and 5. Late Cenozoic (33.9 million years ago to present). (Source: William M. Connolley, June 08, 2012, from Wikimedia.org).

characterized by colder and warmer climate respectively. The last glacial period (LGP), which occurred in the Pleistocene began 115,000 years ago, ended about 11,650 years ago BP. During LGP, episodes of glacier advance and retreat occurred and the Last Glacial Maximum (LGM) was approximately 26,000 years ago. The LGM started receding about 20,000 years ago in northern hemisphere and about 14,500 years ago in Antarctica in southern hemisphere. However, there was a return of a glacial stage (called Younger Dryas) after the Late Glacial Interstadial (14,670 to 12,890 years ago BP). Finally, the end of Younger Dryas (12,890 to 11,650 years ago BP) marked the beginning of the Holocene, which is the current geological epoch.

## THE HOLOCENE EPOCH AND DETERMINATION OF ITS THREE ‘AGES’

The current geological epoch, Holocene, began 11,650 years BP marking completion of the last glacial retreat named ‘Younger Dryas’. The Holocene is warm period, known as MIS 1 (Marine Isotope Stage, Lisiecki and Raymo 2005) in icehouse climate state. Some people consider it an interglacial period within the Pleistocene Epoch, called the Flandrian interglacial (Blij 2012). In July 2018, the International Union of Geological Sciences (IUGS) formally divided the Holocene Epoch into three distinct subsections (Fig. 1): The Greenlandian (11,700 years ago to 8,200 years ago BP), The Northgrippian (8,200 years ago to 4,200 years ago BP) and The Meghalayan (4,200 years ago BP to the present), on the proposal of the International Commission on Stratigraphy (IGS). The Holocene Epoch corresponds with rapid proliferation, growth and impacts of the *Homo sapiens* (the modern human species) worldwide, including all of its written history, technological revolutions, development of major civilizations, and overall significant transition towards urban living in the present (Prokop 2020). The human impact on modern-era Earth and its ecosystems may be considered of global significance for the future evolution of living species, including approximately synchronous lithospheric evidence, or more recently hydrospheric and atmospheric evidence of the human impact.

## THE THREE AGES IN HOLOCENE EPOCH INCLUDING ‘THE MEGHALAYAN AGE’

Prokop (2020) summarized the criteria for defining subdivisions of the units of geological time scale (GTS). The subdivisions are defined with reference to ‘bases’ or lower boundaries (Gradstein et al. 2012), which are drawn using a ‘Global Stratigraphic Section and Point’ (GSSP). For a GSSP, the ‘stratigraphic section’ refers to a deposit (rock, sediment, glacier ice, speleothem) that developed an adequate thickness over time that is chosen as the representative (*i.e.*, type) section, known as the ‘stratotype’. A ‘point’ refers to the location of the marker used to define the boundary within the stratotype. The GSSP markers should ideally be complemented by a series of auxiliary stratigraphic sections that are globally synchronous. The GSSPs must also have an exact location and height or depth, and must be accessible and have provisions for conservation and protection. Proposals for new GSSPs must be formally ratified by the International Union of Geological Sciences (IUGS). Based on these criteria, the term ‘Holocene’, to refer to an epoch, was defined and formally ratified by the IUGS in 2008, although this term has been in use for over

150 years. Subsequently, the IUGS accepted the subdivision of the Holocene Epoch into three new units in 2018. The first two units were named after GSSPs located in Greenland and the third one was derived from the GSSP located in Meghalaya in Northeast India. These three units are ranked as 'Age' within an Epoch.

The base of the Meghalayan Age is dated at 4,200 years BP (Fig. 1). The GSSP is drawn from speleothem in cave Krem Mawmluh (25°15'44"N, 91°42'54"E) in Meghalaya, Northeast India (Fig. 3). This is one of the longest caves in India measuring about 7 km in length with multiple entry points (Fig. 4). The cave is situated at about 1300 m altitude in proximity of Cherrapunji on the southern edge of the Meghalaya Plateau, which is an area of world's heaviest rainfall (Shankar et al. 1991, Pandey et al. 1993) and with highly impoverished soil laid over shallow and thin coal seam (Shankar et al. 1993). The cave is believed to have formed along the contact between a dolomite and sandstone of Eocene age (Fig. 4, Breitenbach et al. 2012, 2015). The location of the cave between the Bay of Bengal and the Tibeto-Himalayan Plateau (Fig. 3), make this area sensitive to climate forcing that govern the monsoon system in Asia (Prokop and Walanus 2015, Huguet et al. 2018). Speleothems (or cave deposits) are secondary mineral deposits formed typically in limestone or dolomite solutional caves (Moore 1952). A "secondary mineral" is one which is derived by a physicochemical reaction from a primary mineral in bedrock or detritus, and/or deposited because of a unique set of conditions in a cave, *i.e.*, the cave environment influences the mineral's deposition (Hill and Forti 1997). The cave is rich in speleothems of various forms, which are formed depending on whether the water drips, seeps, condenses, flows, or ponds. Although the types of speleothems include

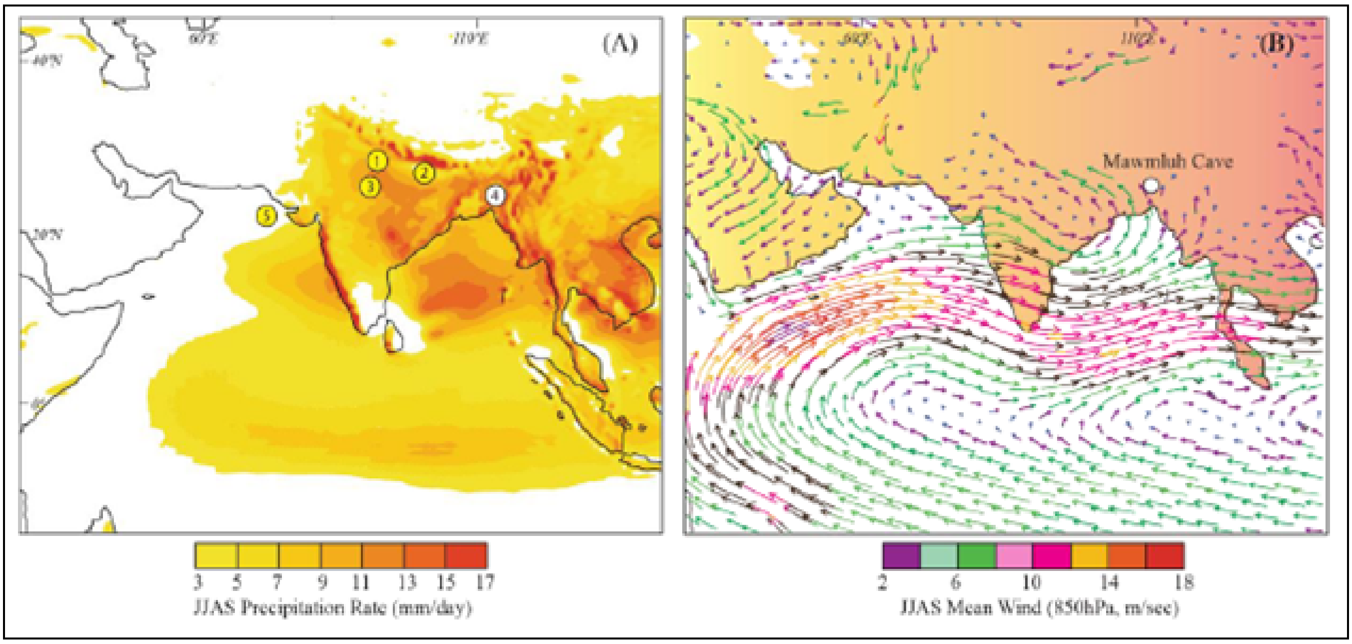


Figure 3. Location map and spatial structure of mean JJAS precipitation and low-level winds. (A) JJAS precipitation from the Tropical Rainfall Measuring Mission (TRMM). The numbering scheme proxy records is as follows: 1, Sahiya cave (Kathayat et al. 2017); 2, Lake Rara (Nakamura et al. 2016); 3, Kotla Dhar (Dixit et al. 2014); 4, Mawmluh Cave in white circle (Berkelhammer et al. 2012); and 5, Indus Delta (Staubwasser et al. 2003). (B) 850 hPa-level monsoon vector from zoomed Laboratoire de Meteorologie Dynamique (LMDZ) general circulation model with telescoping zooming (figure adapted and modified from Sabin et al. 2013). The zoom version shows a well-defined cyclonic circulation with westerlies on the southern flanks and easterly winds on the northern flanks of the Monsoon Trough. The Mawmluh Cave is ideally located to record upstream variations in the overall strength of the ISM. (Source: Kathayat et al. 2018).

Figure 4. An inside view of Krem Mawmluh near Cherrapunji in Meghalaya displaying diverse speleothems. (Photo: Norbert Marwan 2007; Source: https://www.pik-potsdam.de)

dripstone (stalactites or stalagmites), flowstone, cave crystals, speleogens and several others (Cave Popcorn, Cave Pearls, Snottites, Hells Bells), only some of these occur in Mawmluh cave.

## THE ‘4.2 ka BP EVENT’ AND FALL OF ANCIENT CIVILIZATIONS

An important and most recent event of abrupt climate change in the Earth’s history is ‘4.2 ka BP Event’ which is now known to have occurred <“4,200 years ago before present (Zanchetta et al. 2016, Walker et al. 2018). This event is considered a chronological divider between warmer-wetter middle Holocene and cooler-drier late Holocene (Ran and Chen 2019). The ‘4.2 ka BP Event’ is of global significance because it occurred in many regions around the world, including North America, South America, Europe, Africa and Asia (Fig. 5.), and brought about colossal changes in the Earth’s environment (Dalfes et al. 1997, Perry and Hsu 2000, deMenocal 2001, Drysdale et al. 2006). This event was generally characterized by dry and cool climatic conditions (Mayewski et al. 2004). The ‘4.2 ka BP Event’ credibly played a major role in either collapse or in crucial transformation of the four major agrarian ancient civilizations in the Mediterranean, Middle East, Africa, South and East Asia (Fig. 6), *viz.*, Ancient Egyptian civilization in Nile Valley (Stanley et al. 2003, Marshall et. al. 2011), Akkadian Empire of Mesopotamian civilization in the Tigris–Euphrates river system in the northern part of the Fertile Crescent (Weiss et al.1993, Cullen et al. 2000, Weiss 2000, 2016, Weiss and Bradley 2001), Ancient Indian civilization in Indus Valley (Enzel et al. 1999, Staubwasser et al. 2003, Dixit et al. 2014), and Ancient Chinese civilization (Chang 1999, Liu and Feng 2012). Ran and Chen (2019) advocate that ‘4.2 ka BP Event’ played a crucial role in transformation of the Ancient Chinese civilization (Wu and Liu 2001, 2004, Liu and Feng 2012, Wang 2004), because either drying or cooling or drying and cooling at <“4.2 ka BP might not be sufficient to collapse these well-developed cultures in presently warm and wet southern China. However, this event had a huge impact on nearly all of Neolithic cultures in Chinese cultural domain including Qijia Culture in Gansu-Qinghai region, Laohushan Culture in Inner Mongolian region, Liangzhu Culture in the middle and lower reaches of the Yangtze River, Longshan

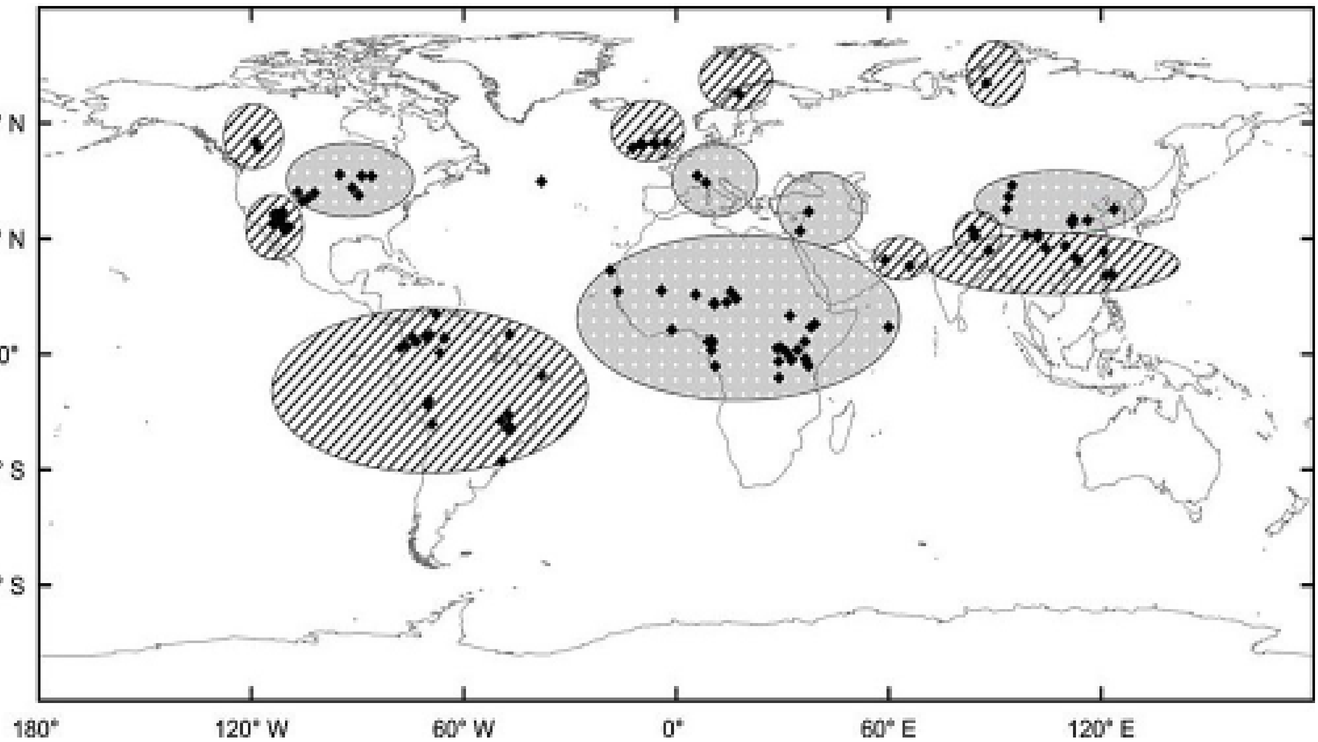


Figure 5. Global distribution of the 4.2 kiloyear event. The hatched areas were affected by wet conditions or flooding, and the dotted areas by drought or dust storms. (Source: Jianjun Wang, Liguang Sun, Liqi Chen, Libin Xu, Yuhong Wang and Xinming Wang 2019; Wikimedia.org).

Culture in Shandong region and Shijiahe Culture in Hunan-Hubei region (Liu and Feng 2012, Wang 2004, Wu and Liu 2001, 2004).

The '4.2 ka BP Event' is generally described as an approximately two to three centuries-long interval of drought (Berkelhammer et al. 2012, Dixit et al. 2014, 2018, Nakamura et al. 2016), which was superimposed on a longer-term insolation-induced weakening of the Indian summer monsoon (ISM) during the Holocene (Hong et al. 2014, 2018, Kathayat et al. 2017). The oxygen isotope record from the speleothem correlates the '4.2 ka BP Event' with a markedly weakened Asian summer monsoon spanning ~200 years (Berkelhammer et al. 2012). This event was reported to have occurred in many regions around the world, especially in the mid and low latitudes, and was generally characterised by dry and cool climatic conditions (Thompson et al. 2002, Mayewski et al. 2004, Booth et al. 2005). The newer evidences suggest that the '4.2 ka BP Event' was not a singular multi-centennial drought, but it spanned an approximately 300-year long period (4.2 to 3.9 ka BP) of major climate change across the globe based on new oxygen isotope data from a pair of speleothems (ML.1 and ML.2) from Mawmluh Cave, Meghalaya, India (Fig. 3, Kathayat et al. 2018). The high-resolution record of ISM variability during a period (4.44 and 3.78 ka BP) suggest that the ISM intensity abruptly decreased at <"4.0 ka (<" ±13 years), marking the onset of a multi-centennial period of relatively reduced ISM, which was punctuated by at least two multi-decadal droughts between <"4.0 and 3.9 ka BP (Kathayat et al. 2018).

## THE CONTEXT OF ANTHROPOCENE

'Anthropocene' is not yet an officially approved term as a section of the geological time, but it is informally and widely used these days to refer to a geological epoch dating from the commencement of significant human impact on Earth's geology and ecosystems (Steffen et al. 2007, Vince 2011, Davison 2019, Soriano 2020). While some propose the start date of the Anthropocene from the commencement of the Agricultural Revolution about 12 to 15 thousand years ago, the others offer it from detonation of the


| 1. North America | 2. South America | 3. Europe | 4. Africa | 5. Asia |
|---|---|---|---|---|
| 1. South Rhody Peat | 2. Huascarán Ice Core | 3. Renella Stalagmite | 4. Kilimanjaro Ice Core | 5. Mawmluh Cave |
| Groundwater Level (cm) | Insoluble Dust (10[illegible]) | $\delta^{13}C$ (‰, VPDB) | Insoluble Dust (10[illegible]) | $\delta^{18}O$ (‰, VPDB) |

Figure 6. A: Location map of five representative sequences (1 through 5) containing the '4.2 ka BP Event' and the domains of the four ancient civilizations: a, Ancient Egyptian civilization; b, Mesopotamian civilization; c, Ancient Indian civilization; and d, Ancient Chinese civilization. (Source: Ran and Chen 2019).

first atomic bomb on July 16, 1945, which is called as the Trinity test, with many other proposals in between of these two dates. An American biologist working on diatoms in University of Michigan, Professor Eugene F. Stoermer, coined the term 'Anthropocene' in early 1980s to refer to the impact and evidence for the effects of human activity on the planet Earth. The usage of the term gained popularity after a Nobel Prize winning Dutch atmospheric chemist, Professor Paul Crutzen, in the year 2000, proposed Anthropocene to constitute a geological epoch based on his research on climate change. The International Commission on Stratigraphy (ICS) constituted an interdisciplinary research group called 'The Anthropocene Working Group (AWG)' in 2009 including Paul Crutzen as an expert besides physical geographer Simon Turner (as Secretary), geologist Colin Neil Waters (as Chair) and several others dedicated to the study of the Anthropocene as a geological time unit. This is one of the four working groups of the Subcommission on Quaternary Stratigraphy of ICS. The main objective of the AWG is to establishing when, where, and how to locate the lower boundary of the Anthropocene. The latest update here is that as on July, 2020, the ICS as well as the IUGS did not formalize Anthropocene a geological epoch. Hence, the search for geological markers to delineate Anthropocene continues.

Many authors informally use the term 'Anthropocene' synonymous to 'Holocene' or in a way to refer to a section of Holocene which in most cases falls in 'The Meghalayan Age' in which human-environment interaction has been continuously intensifying owing to human population rise. The biologists are most concerned for environmental and climate change led by human activities as these changes are causing rapid loss of species, which is multiple times faster than the background extinction rate as well as the rate of appearance of newer species or speciation. The latest estimates reckon 27% of all assessed species threatened (IUCN 2020). The species which are not labelled threatened are also in peril as their populations are continuously dwindling and geographical distribution is retreating (Shivanna 2020, Shankar 2021), barring only some invasive species (Shankar et al. 2011). The estimates of IUCN are biased towards animal species as assessments of only limited number of plant species are available so far. Notwithstanding, 34% of conifers are threatened among plant groups which is greater than the average for animal groups, and more similar examples may emerge.

Most discussions on human-environment interactions lead to the general notion that the diversity of species will decrease further in ensuing decades (Shivanna 2020). While the threat for existing species on the Earth is looming large in Anthropocene, some visualize that the impact of climate change may also accelerate the rate of speciation (Thomas 2015, Levin 2019). For instance, the estimates find that the numbers of newer species that have arisen in Europe over the past three centuries are greater than the numbers of species documented as extinct during the same period (Thomas 2015). This increase is attributed to modern interventions in agriculture and horticulture, and human-mediated transfer of species across regions, triggering polyploid species due to hybridization with nonnatives (Vellend et al. 2017). Levin (2019) and Gao (2019) predict that auto- and allo-polyploidy shall be the primary modes of speciation in next 500 years and the proportion of polyploid species would exceed one-half of the total described species. Otto (2018) categorizes mechanisms impacting speciation rates into human-altered niches, human-altered contact and human-altered selection with a view to expect more rapid speciation in the Anthropocene. Levin (2019) argues that the environmental stresses induced due to climate change are likely to trigger higher rates of speciation through mutations and other genetic changes. Similarly, the responses of crop species to climate change shall be important to watch (Gornall et al. 2010). Would climate change induce higher levels of polyploidy or other genetic changes in crop species in the coming decades leading to the evolution of new genotypes/varieties/species so that they are able to sustain productivity as well as the quality of food grains for nutrition security of humans?

## CONCLUSIONS

This commentary highlights that the cave 'Krem Mawmluh' in Meghalaya, India offers a high-resolution history of ISM during a period contemporaneous with the '4.2 BP ka BP Event' which had an impact on human societies across the globe and played an important role in the collapse of at least three of the four major ancient civilizations. The Northeast India has recorded the Holocene climate change events in other proxy records as well. Besides Mawmluh Cave, the catchment of Pankang Teng Tso (PT Tso) Lake at an altitude of 3935 m amsl in the Tawang district of Arunachal Pradesh evinced a synchronous pattern of Holocene climate changes in palynological, environmental magnetic and carbon isotope data (Mehrotra et al. 2019). The vegetation vis–à–vis climate varied throughout the Holocene and cold–dry conditions along with sub-alpine vegetation prevailed in Tawang region around the '4.2 ka BP Event'. Human activities and environmental changes in Tawang district during the Holocene probably impacted the vegetation. These findings open up a new vista for investigation into the role of ISM in shaping forest ecosystems and biodiversity in Northeast India, which we inherit today.

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**Conflict of interest**: The author declares that he has no conflict of interest.

## REFERENCES

Berkelhammer, M., Sinha, A., Stott, L., Cheng, H., Pausata, F. and Yoshimura, K. 2012. An abrupt shift in the Indian monsoon 4000 years ago. Geophysical Monograph Series, 198: 75–88.

Blij, H. de 2012. Why geography matters: more than ever. Oxford University Press. 368pp.

Booth, R.K., Jackson, S.T., Forman, S.L., Kutzbach, J.E., Bettis III., E.A., Kreig, J. and Wright, D.K. 2005. A severe centennial-scale drought in mid-continental North America 4200 years ago and apparent global linkages. Holocene, 15: 321–328.

Breitenbach, S.F.M., Lechleitner, F.A., Meyer, H., Diengdoh, G., Mattey, D. and Marwan, N. 2015. Cave ventilation and rainfall signals in dripwater in a monsoonal setting – a monitoring study from NE India. Chemical Geology, 402: 111–124.

Breitenbach, S.F.M., Rehfeld, K., Goswami, B., Baldini, J.U.L., Ridley, H.E., Kennett, D.J., Prufer, K.M., Aquino, V.V., Asmerom, Y., Polyak, V.J., Cheng, H., Kurths, J. and Marwan, N. 2012. Constructing Proxy Records from Age models (COPRA). Climate of the Past, 8: 1765–1779.

Chang, K.C. 1999. China on the eve of the Historical Period. Pages: 37-73, In: Loewe, M. and Shaughnessy, E. L. (Editors.), The Cambridge History of Ancient China – From the Origins of Civilization to 221 BC. Cambridge University Press, New York.

Cullen, H.M., deMenocal, P.B., Hemming, S., Hemming, G., Brown, F.H., Guilderson, T. and Sirocko, F. 2000. Climate change and the collapse of the Akkadian empire: evidence from the deep sea. Geology, 28: 379–382.

Dalfes, H., Kukla, G. and Weiss, H. 1997. Third Millennium BC Climate Change and Old World Collapse (NATO ASI Series 1, 49). Springer Publishing, New York.

Davison, N. 2019. The Anthropocene epoch: have we entered a new phase of planetary history? The Guardian, 30 May, 2019.

deMenocal, P. 2001. Cultural responses to climate change during the late Holocene. Science, 292: 667–673.

Dixit, Y., Hodell, D.A., Giesche, A., Tandon, S.K., Gázquez, F., Saini, H.S., Skinner, L.C., Mujtaba, S.A., Pawar, V. and Singh, R.N. 2018. Intensified summer monsoon and the urbanization of Indus Civilization in northwest India. Scientific Reports, 8: 4225–2018.

Dixit, Y., Hodell, D.A. and Petrie, C.A. 2014. Abrupt weakening of the summer monsoon in northwest India~ 4100 yr ago. Geology, 42: 339–342.

Drysdale, R., Zanchetta, G., Hellstrom, J., Maas, R., Fallick, A., Pickett, M., Cartwright, I. and Piccini, L. 2006. Late Holocene drought responsible for the collapse of Old World civilizations is recorded in an Italian cave flowstone. Geology, 34: 101–104.

Enzel, Y., Ely, L.L., Mishra, S., Ramesh, R., Amit, R., Lazar, B., Rajaguru, S.N., Baker, V.R. and Sandler, A. 1999. High-resolution Holocene environmental changes in the Thar Desert, northwestern India. Science, 284: 125–128.

Gao, J.G. 2019. Dominant plant speciation types. A commentary on: plant speciation in the age of climate change. Annals of Botany, 124(5): iv–vi. https://doi.org/10.1093/aob/mcz174.

Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., Willett, K. & Wiltshire, A. 2010. Implications of climate change for agricultural productivity in the early twenty-first century. Philosophical Transactions of the Royal Society Series B, 365(1554): 2973–2989. https://doi.org/10.1098/rstb.2010.0158

Gradstein, F.M., Ogg, J.G., Schmitz, M., Ogg, G. (eds.) 2012. The geologic time scale 2012. Elsevier.

Hill, C.A. and Forti, P. 1997. Cave Minerals of the World. 2nd edition. Huntsville, Alabama: National Speleological Society Inc. pp. 217, 225.

Hong, B., Hong, Y., Uchida, M., Shibata, Y., Cai, C., Peng, H., Zhu, Y., Wang, Y. and Yuan, L. 2014. Abrupt variations of Indian and East Asian summer monsoons during the last deglacial stadial and interstadial. Quaternary Science Reviews, 97: 58-70.

Hong, B., Uchida, M., Hong, Y., Peng, H., Kondo, M. and Ding, H. 2018. The respective characteristics of millennial-scale changes of the India summer monsoon in the Holocene and the Last Glacial. Palaeogeography, Palaeoclimatology, Palaeoecology, 496: 155-165.

Huguet, C., Routh, J., Fietz, S., Lone, M.A., Kalpana, M.S., Ghosh, P., … Rangarajan, R. 2018. Temperature and monsoon tango in a tropical stalagmite: last glacial-interglacial climate dynamics. Scientific Reports, 8(1): 5386. https://doi.org/10.1038/s41598-018-23606-w

IUCN 2020. The IUCN Red List of threatened species. Version 2020–1. https://www.iucnredlist.org (Accessed on 29.01.2021).

Kathayat, G., Cheng, H., Sinha, A., Yi, L., Li, X., Zhang, H., Li, H., Ning, Y. and Edwards, R.L. 2017. The Indian monsoon variability and civilization changes in the Indian subcontinent. Science Advances, 3, e1701296, https://doi.org/10.1126/sciadv.1701296.

Kathayat, G., Cheng, H., Sinha, A., Berkelhammer, M., Zhang, H., Duan, P., Li, H., Li, X., Ning, Y. and Edwards, R.L. 2018. Evaluating the timing and structure of the 4.2 ka event in the Indian summer monsoon domain from an annually resolved speleothem record from Northeast India. Climate of the Past, 14: 1869-1879.

Levin, D.A. 2019. The role of chromosomal change in plant evolution. Oxford University Press, New York.

Liu, F.G. and Feng, Z.D. 2012. A dramatic climatic transition at <"4000 cal. yr BP and its cultural responses in Chinese cultural domains. Holocene, 22: 1181–1197.

Luhr, J.F. (ed.) 2007. Earth. Dorling Kindersley Publishing Staff. ISBN 978-0-7566-3332-5.

Montanez, I. and Soreghan, G.S. 2006. Earth's Fickle Climate: Lessons Learned from Deep-Time Ice Ages. Geotimes, 51: 24–27.

Lisiecki, L.E. and Raymo, M.E. 2005. A Pliocene Pleistocene stack of 57 globally distributed benthic ä18O records. Paleoceanography and Paleoclimatology, 20: PA1003.

Marshall, M.H., Lamb, H.F., Huws, D., Davies, S.J., Bates, R., Bloemendal, J., Boyle, J., Leng, M.J., Umer, M. and Bryant, C. 2011. Late Pleistocene and Holocene drought events at Lake Tana, the source of the Blue Nile. Global and Planetary Change, 78: 147–161.

Mayewski, P.A., Rohling, E.E., Stager, J.C., Karlén, W., Maasch, K.A., Meeker, L.D., Meyerson, E.A., Gasse, F., van Kreveld, S., Holmgren, K., Lee-Thorp, J., Rosqvist, G., Rack, F., Staubwasser, M., Schneider, R.R. and Steig, E.J. 2004. Holocene climate variability. Quaternary Research, 62: 243–255.

Mehrotra, N., Shah, S.K., Basavaiah, N., Laskar, A.H. and Yadava, M. 2019. Resonance of the '4.2ka event' and terminations of global civilizations during the Holocene, in the palaeoclimate records around PT Tso Lake, Eastern Himalaya. Quaternary International, 507: 206-216.

Moore, G.W. 1952. Speleothems – a new cave term. National Speleological Society News, 10(6): 2.

Nakamura, A., Yokoyama, Y., Maemoku, H., Yagi, H., Okamura, M., Matsuoka, H., Miyake, N., Osada, T., Adhikari, D.P., Dangol, V., Ikehara, M., Miyairi, Y. and Matsuzaki, H. 2016. Weak monsoon event at 4.2 ka recorded in sediment from Lake Rara, Himalayas. Quaternary International, 397: 349–359.

Otto, S.P. 2018. Adaptation, speciation and extinction in the Anthropocene. Proceedings of the Royal Society Series B, 285(1891): 20182047. https://doi.org/10.1098/rspb.2018.2047

Pandey, H.N., Tripathi, R.S. and Shankar, U. 1993. Nutrient cycling in an excessively rainfed subtropical grassland at Cherrapunji. Journal of Biosciences, 18(3): 395-406.

Perry, C.A., and Hsu, K.J., 2000. Geophysical, archaeological, and historical evidence support a solar-output model for climate change. Proceedings of National Academy of Sciences, USA, 97: 12433–12438.

Prokop, P. 2020. Where the Meghalayan meets the anthropocene: stratigraphic signals of human-environmental interactions on the periphery of Indian civilisation. Geographia Polonica, 93(4): 505-523.

Prokop, P. and Walanus, A. 2015. Variation in the orographic extreme rain events over the Meghalaya Hills in northeast India in the two halves of the twentieth century. Theoretical and Applied Climatology, 121(1-2): 389-399.

Ran, M. and Chen, L. 2019. The 4.2 ka BP climatic event and its cultural responses. Quarternary International, 521: 158-167.

Sabin, T., Krishnan, R., Ghattas, J., Denvil, S., Dufresne, J.-L., Hourdin, F. and Pascal, T. 2013. High resolution simulation of the South Asian monsoon using a variable resolution global climate model. Climate Dynamics, 41: 173–194.

Shankar, U. 2021. Enumeration of the flora of Northeast India – Onelist of over 10,000 taxa of flowering plants. AFB Flora Series on Flowering Plants of the Indian Subcontinent, Volume #1. Arshuma Famous Books, Agra, India. pp. x+486. (ISBN: 978-93-5445-467-7).

Shankar, U., Tripathi, R.S. and Pandey, Ç.Í. 1991. Structure and seasonal dynamics of humid tropical grasslands in India. Journal of Vegetation Science, 2: 711-714.

Shankar, U., Boral, L., Pandey, H.N. and Tripathi, R.S. 1993. Degradation of land due to coal mining and its natural recovery pattern. Current Science, 65(9): 680-687.

Shankar, U., Yadava, A.S., Rai, J.P.N. & Tripathi, R.S. 2011. Status of alien plant invasions in north-eastern region of India. Pages: 174-188, In: Bhatt, J.R., Singh, J.S., Singh, S.P., Tripathi, R.S. and Kohli, R.K. (Editors.), Invasive alien plants: an ecological appraisal for the Indian subcontinent. CABI, UK.

Shivanna, K.R. 2020. Speciation in flowering plants: an overview. Rheedea, 30(4): 409-426.

Soriano, C. 2020. On the Anthropocene formalization and the proposal by the Anthropocene Working Group. Geologica Acta, 18(6): 1-10.

Staubwasser, M., Sirocko, F., Grootes, P. and Segl, M. 2003. Climate change at the 4.2 ka BP termination of the Indus valley civilization and Holocene south Asian monsoon variability. Geophysical Research Letters, 30.

Stanley, J.-D., Krom, M.D., Cliff, R.A. and Woodward, J.C. 2003. Nile flow failure at the end of the Old Kingdom, Egypt: strontium isotopic and petrologic evidence. Geoarchaeology: An International Journal, 18: https://doi.org/10.1002/gea.10065.

Steffen, W., Crutzen, P.J. and McNeill, J.R. 2007. The Anthropocene: are humans now overwhelming the great forces of Nature? AMBIO, 36(8): 614–621.

Thomas, C.D. 2015. Rapid acceleration of plant speciation during the Anthropocene. Trends in Ecology and Evolution, 30(8): 448–455. https://doi.org/10.1016/j.tree.2015.05.009

Thompson, L.G., Mosley-Thompson, E., Davis, M.E., Henderson, K.A., Brecher, H.H., Zagorodnov, V.S., Mashiotta, T.A., Lin, P.N., Mikhalenko, V.N., Hardy, D.R. and Beer, J. 2002. Kilimanjaro ice core records: evidence of Holocene climate change in tropical Africa. Science, 298: 589–593.

Vellend, M., Baeten, L., Becker-Scarpitta, A., Boucher-Lalonde, V., Mccune, J.L., Messier, J., Myers-Smith, I.H. & Sax, D.F. 2017. Plant biodiversity change across scales during the Anthropocene. Annual Review of Plant Biology, 68: 563–586. https://doi.org/10.1146/annurev-arplant-042916-040949

Vince, G. 2011. An Epoch Debate. Science, 334(6052): 32–37.

Walker, J.D., Geissman, J.W., Bowring, S.A., and Babcock, L.E., compilers, 2018. Geologic Time Scale v. 5.0: Geological Society of America, https://doi.org/10.1130/2018.CTS005R3C.

Wang, W. 2004. Discussion on the large-scale cultural changes at <“2000 BC in China. Archaeology, 1: 67–77. (in Chinese with English Abstract).

Weiss, H. 2016. Global megadrought, societal collapse and resilience at 4.2-3.9 ka BP across the Mediterranean and west Asia. PAGES, 24: 62–63.

Weiss, H. 2000. Beyond the Younger Dryas: Collapse as adaptation to abrupt climate change in ancient West Asia and the Eastern Mediterranean. Pages: 63-74, In: Bawden, G. and Reycraft, R. (Editors), Environmental Disaster and the Archaeology of Human Response. University of New Mexico Press, Albuquerque: Maxwell Museum of Anthropology.

Weiss, H. and Bradley, R. 2001. What drives societal collapse? Science, 291: 609–610.

Weiss, H., Courty, M.-A., Wetterstrom, W., Guichard, F., Senior, L., Meadow, R. and Curnow, A. 1993. The genesis and collapse of third millennium north Mesopotamian civilization. Science, 261: 995–1004.

Wu, W.X. and Liu, T.S. 2001. 4000 a B.P. event and its implications for the origin of ancient Chinese civilization. Quaternary Science, 21: 443–451. (in Chinese with English Abstract).

Wu, W.X. and Liu, T.S. 2004. Possible role of the ‘holocene event 3’ on the collapse of neolithic cultures around the Central Plain of China. Quaternary International, 117: 153–166.

Zanchetta, G., Regattieri, E., Isola, I., Drysdale, R.N., Bini, M., Baneschi, I. and Hellstrom, J.C. 2016. The so-called “4.2 event” in the central Mediterranean and its climatic teleconnections. Alpine Mediterranean Quaternary, 29: 5–17.

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