Pilot study - Field Trip Report **September 06, 2017**

Stalagmite-inferred past precipitation and climate records since the last glacial time on Christmas Island

Project leaders: Dr. Chuan-Chou Shen of the Department of Geosciences, National Taiwan University, Taipei, Taiwan ROC

Dr. Jean-Paul A. Hobbs of the Department of Environment and Agriculture, Curtin University, Perth, Western Australia 6845, Australia.

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Background and rationale

Precipitation in Christmas Island is controlled by the migration of the Intertropical Convergence Zone (ITCZ) and Indian Monsoon (IM) system. The ITCZ, the heaviest rain belt on earth, provides water resources for most populations in the world. Collapses of human civilizations, such as Maya and Chinese Dynasties could be caused by persistent droughts, associated with substantial ITCZ migrations. The buildup of greenhouse gases in the atmosphere was suggested to potentially move the ITCZ band in the next century (Sachs, et al., 2009). An in-depth understanding of the position, structure, and migration of the ITCZ is, thus, clearly important for the global climate and sustainable socioeconomic development of human societies.

The IM is an important component of the global climate system, and it plays a vital role in transporting heat and moisture from tropical oceans to the higher latitudes. It is acknowledge that the strength of the IM paced by solar forcing and strongly influenced by changes in northern high-latitude climatic condition. Its past variability was revealed by Chinese cave records, such as Xiaobailong (Cai et al., 2006; 2015) and Hulu (Wang et al. 2001). Evidences from 252-kyr Indian summer monsoon records (Cai et al., 2015) suggest that the ITCZ in the Indian Ocean was predominately driven by precessional forcing (~20 kyr) and related to glacial-interglacial cycles. Since the last glacial time, monsoonal precipitation was also characterized by millennial-scale oscillations, induced by Heinrich events in the North Atlantic. As for the East Asian winter monsoon, the counterpart of the Australian summer monsoon, Japanese stalagmite records (Sone et al., 2013) revealed that winter monsoonal precipitation might have been amplified with intensification of the Tsushima Warm Current that enhanced the land-sea thermal contrast during winter season. However, limited records from the islands on Indian Ocean located at the core of the ITCZ hamper the insight understanding of its natural variability and the influences of forcings originated from North Atlantic on low-latitude climate in the southern hemisphere. Christmas Island, located in Indian Ocean ITCZ, and its location and relatively long history is ideal for conducting this paleoclimate research on interglacial variation in ITCZ position and precipitation.

Due to its relatively long history and isolation, Christmas Island is covered in extensive rainforest that contains an extraordinary unique diversity of plants and animals. This includes hundreds of endemic species and the greatest diversity of land crabs in the world. The land crabs are particularly important because they play a key ecological role in maintaining rainforest biodiversity. The rainforest ecosystem is reliant on rainfall during the monsoon season (December to March). Furthermore, the annual spawning migration of millions of land crabs is triggered by the onset of the monsoonal season, and the amount of rainfall and associated climatic conditions determine survival rates of spawning adults and the number of offspring that replenish the rainforest. Therefore, understanding precipitation and the monsoonal patterns is fundamental to predicting how Christmas Island's rainforest ecosystem will be affected by climate change.

Stalagmites contain a historical record of past climatic conditions and new geochemical analyses of stalagmites can reveal how changes in climate affect precipitation rates and monsoon activity. These sophisticated analyses provide an accurate and ideal method for studying climate history provided the stalagmite contains geochemical signals that are of sufficient quality. Christmas Island has a network of cave systems that contain stalagmites. If these stalagmites have suitable geochemical properties then they will provide the ideal way to determine how changes in climate affect the amount of precipitation and monsoonal activity experienced on Christmas Island. Furthermore, these stalagmites will provide an important reference point that can be used in conjunction with stalagmites analysed in other regions to provide a global picture of climate change effects. Therefore, the aim of this pilot study was to determine whether the stalagmites at Christmas Island contain geochemical properties that make them suitable for analyses of the Island's climate records.

Methods - cave surveys

We visited the Headquarters of Christmas Island National Park (CINP) in the morning of April 13, 2016 after arrival on April 12. The outline for the pilot study and conditions for sampling stalagmites were discussed with Head Ranger Rob Muller. Following these discussions we surveyed Upper Daniel Roux Cave (outside CINP) in the afternoon of April 14 and Smith's Cave on April 15 (within CINP). These two caves have narrow entrances and long narrow (0.5-2 m) passages (> 200 m), which increases the chances of finding stalagmites that could potentially be suitable for paleoclimate study. We collected four small test stalagmites in Upper Daniel Roux Cave (Fig. 1). In Smiths Cave, two broken test stalagmites were picked off the ground (Fig. 2).

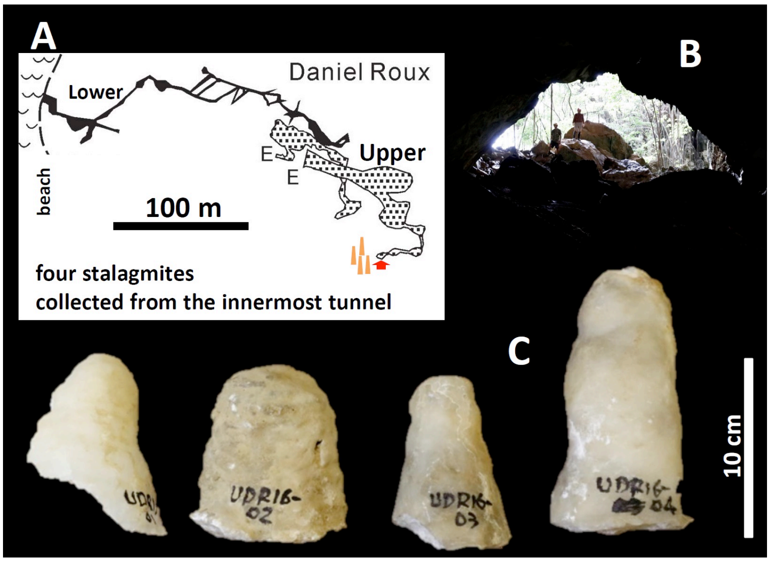

Figure 1. (A) A map of Lower and Upper Daniel Roux Cave. Red arrow denotes the end of passage of Upper Daniel Roux Cave, where four small stalagmites were collected (brown). (B) The entrance of Upper Daniel Roux Cave. (C) Photos of four small test stalagmites taken from the cave.

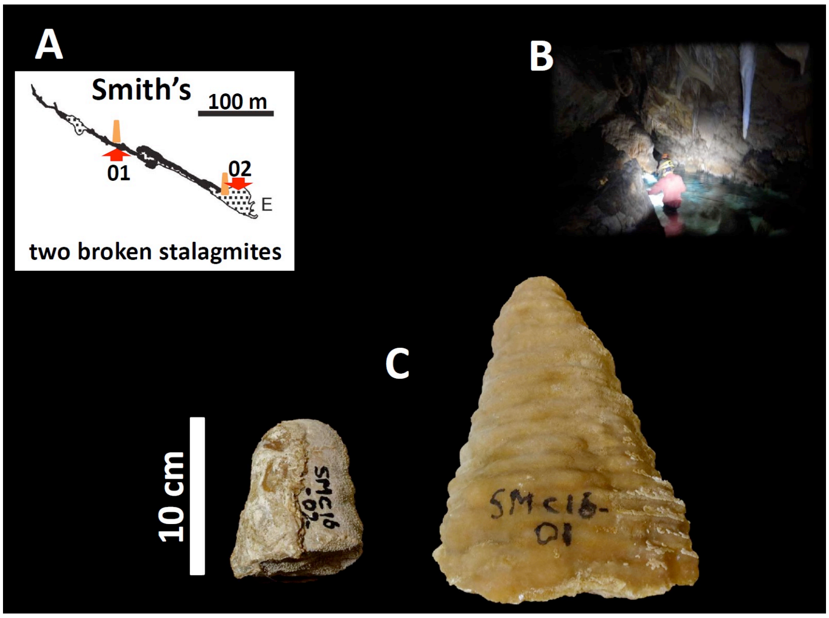

Figure 2. (A) A map of Smith's Cave. Red arrow denotes the sites where two small broken stalagmites were picked off the ground (brown). (B) The passage in the cave. (C) Photos of two small broken test stalagmites taken from the cave.

Methods - test stalagmites

It is vitally important to have a better understanding of the past climate in order to predict the future trend of both regional and global climate changes. Stalagmites have been used as a natural environment archive for providing high-resolution records to past climate change. Taking advantage of the recently established U-Th dating techniques for providing precise dating on stalagmites; therefore, leads us to a better understanding of the past. These new geochemical analyses can only be conducted on stalagmites with suitable properties. To determine if the Christmas Island stalagmites are suitable for this analyses, powdered subsamples from the top and bottom layers of all the stalagmites from Upper Daniel Roux Cave and Smith's Cave were drilled from the polished surface of halved samples (Figs. 3,4). The subsamples were tested for U-Th chemistry (Shen et al., 2003) and instrumental analysis on a multi-collector inductively coupled mass spectrometer (Thermo Fisher Neptune) at the High-Precision Mass Spectrometry and Environment Change Laboratory (HISPEC), National Taiwan University (Shen et al., 2012).

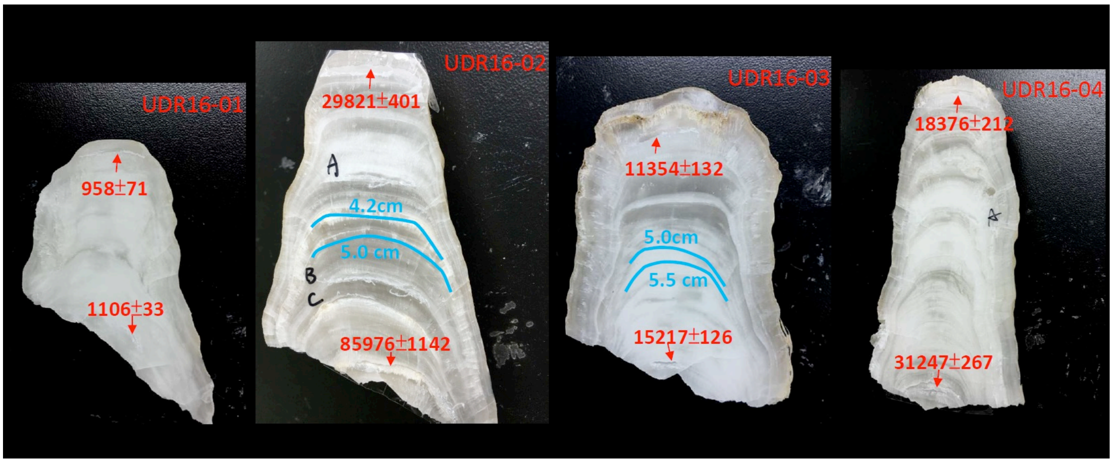

Figure 3. U-Th ages of the top and bottom parts of four test stalagmites from Upper Daniel Roux Cave. Blue curves denote the layers used for Hendy Test (1971).

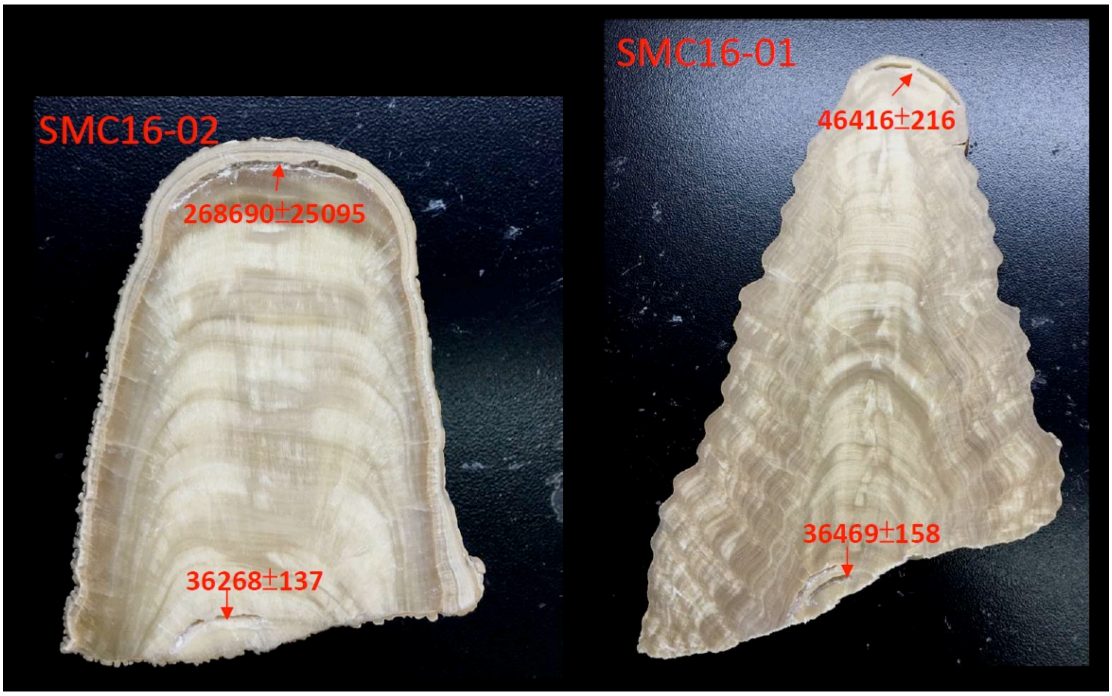

Figure 4. U-Th ages of the top and bottom parts of two test stalagmites from Smith's Cave.

Table 1. Uranium and Thorium isotopic compositions and ^{230}Th ages for Chrisatmas Island speleothem samples by MC–ICPMS, Thermo Electron Neptune, at NTU.

Sample ID	^{238}U ppm^{a}	^{232}Th ppm	$\delta^{234}U$ measured^{a}	$[^{230}Th/^{238}U]$ activity^{c}	$[^{230}Th/^{232}Th]$ ppm^{d}	Age uncorrected	Age corrected ^{c,e}	$\delta^{234}U_{initial}$ corrected^{b}
SMC16-01 Top	230.86 ± 0.31	418 ± 12	-16.2 ± 1.5	0.34099 ± 0.00114	3107 ± 93	46,464 ± 214	46,416 ± 216	-18.4 ± 1.7
SMC16-01 Bottom	293.80 ± 0.38	18 ± 11	-12.7 ± 1.5	0.28048 ± 0.00092	76962 ± 48139	36,470 ± 158	36,469 ± 158	-14.1 ± 1.6
SMC16-02 Top	406.13 ± 0.55	169142 ± 2323	22.9 ± 1.5	0.9506 ± 0.0196	37.63 ± 0.93	279,726 ± 27058	268,690 ± 25095	48.9 ± 5.1
SMC16-02 Bottom	277.51 ± 0.39	24 ± 11	13.5 ± 1.6	0.28697 ± 0.00078	53772 ± 23887	36,270 ± 137	36,268 ± 137	15.0 ± 1.8
UDR16-01 Top	69.558 ± 0.085	37 ± 12	-100.1 ± 1.5	0.007995 ± 0.000572	248 ± 82	973 ± 70	957.6 ± 70.5	-100.3 ± 1.5
UDR16-01 Bottom	145.58 ± 0.18	6 ± 11	-99.7 ± 1.5	0.009091 ± 0.000266	3907 ± 7551	1,107 ± 33	1,105.7 ± 32.6	-100.0 ± 1.5
UDR16-02 Top	27.317 ± 0.040	277.0 ± 9.3	-30.6 ± 2.3	0.23353 ± 0.00247	380 ± 13	30,099 ± 377	29,821 ± 401	-33.2 ± 2.5
UDR16-02 Bottom	58.189 ± 0.074	1964 ± 11	-33.4 ± 1.8	0.52886 ± 0.00403	258.4 ± 2.4	86,909 ± 1055	85,972 ± 1146	-42.6 ± 2.2
UDR16-03 Top	63.754 ± 0.077	84 ± 11	-44.8 ± 1.7	0.09467 ± 0.00101	1191 ± 153	11,391 ± 130	11,354 ± 132	-46.3 ± 1.8
UDR16-03 Bottom	64.461 ± 0.083	62 ± 10	-40.5 ± 1.6	0.12507 ± 0.00093	2143 ± 343	15,243 ± 126	15,217 ± 126	-42.3 ± 1.7
UDR16-04 Top	74.63 ± 0.10	511 ± 11	-38.5 ± 1.6	0.15035 ± 0.00139	362.1 ± 8.4	18,565 ± 190	18,376 ± 212	-40.6 ± 1.7
UDR16-04 Bottom	56.526 ± 0.072	73 ± 13	-43.8 ± 1.8	0.23800 ± 0.00168	3041 ± 552	31,283 ± 266	31,247 ± 267	-47.9 ± 2.0

Chemistry was performed on Aug.16th, 2013 (Shen et al., 2003), and instrumental analysis on MC-ICP-MS (Shen et al., 2012).
Analytical errors are 2σ of the mean.
$^{a}[^{238}U] = [^{235}U]$ x 137.818 (±0.65‰) (Hiess et al., 2012); $\delta^{234}U = ([^{234}U/^{238}U]_{activity} - 1) \times 1000$.
^{b} $\delta^{234}U_{initial}$ corrected was calculated based on ^{230}Th age (T), i.e., $\delta^{234}U_{initial} = \delta^{234}U_{measured}\, X\, e^{\lambda234*T}$, and T is corrected age.
^{c} $[^{230}Th/^{238}U]_{activity} = 1 - e^{-\lambda_{230}T} + (\delta^{234}U_{measured}/1000)[\lambda_{230}/(\lambda_{230} - \lambda_{234})](1 - e^{-(\lambda_{230} - \lambda_{234})T})$, where T is the age.
Decay constants are 9.1705 x 10^{-6} yr^{-1} for ^{230}Th, 2.8221 x 10^{-6} yr^{-1} for ^{234}U (Cheng et al., 2013), and 1.55125 x 10^{-10} yr^{-1} for ^{238}U (Jaffey et al., 1971) .
^{d} The degree of detrital ^{230}Th contamination is indicated by the $[^{230}Th/^{232}Th]$ atomic ratio instead of the activity ratio.
^{e} Age corrections for samples were calculated using an estimated atomic $^{230}Th/^{232}Th$ ratio of 4 ± 2 ppm.
Those are the values for a material at secular equilibrium, with the crustal $^{232}Th/^{238}U$ value of 3.8. The errors are arbitrarily assumed to be 50%.

For test stalagmites in Upper Daniel Roux Cave and Smith's Cave, ^{238}U ($[^{238}U]$) and $[^{232}Th]$ contents are 10s-150 ppb and 10s-1000s ppt, respectively. Uncertainty of corrected ^{230}Th dates ranges from ±0.1 to ±1.0 kyr. Thorium levels are very low and the cave stalagmites are very clean and suitable for U-Th dating. Hendy Test shows that the cave stalagmites from the innermost tunnel can capture natural hydroclimatic signal and are suitable for paleoclimate study.

For stalagmites in Smith's Cave, $[^{238}U]$ and $[^{232}Th]$ contents are 100s ppb and 10s-100s ppt, respectively, except for the top subsample of SMC16-2. The U-Th isotopic data and ages determined for all stalagmites are listed in Table 1. The ages for top layers of the two broken stalagmites are apparently older than the bottom layers. The reversal ages indicates that the upper parts of the stalagmites were re-crystalized. Apparently, chemical and isotopic changes through a diagenesis process and the two broken stalagmites, picked off the ground, are not suitable for further study.

Conclusion

On the basis of our geochemical analyses on the collected test specimens, the stalagmites within Upper Daniel Roux Cave are suitable for examining historical climate records.

Therefore, we would like to organise an official field trip to conduct a formal study of the stalagmites in Upper Daniel Roux Cave in the near future. We will propose to collect four stalagmites, which can cover the entire Holocene and the last glacial time. They will be used to reconstruct regional precipitation history on Christmas Island and the migration of the ITCZ under Asian-Australian monsoon realm and impact of high-latitude forcings from the northern and southern hemisphere. While the broken stalagmites from Smith's Cave were not suitable for geochemical analyses, there are numerous other caves at Christmas Island and we would like to test stalagmites from 1-2 new caves. Collectively, the climate information revealed by the geochemical analyses of all the collected stalagmites with be critical to predicting how climate change will affect precipitation and monsoonal activity on Christmas Island. This greater understanding will aid management efforts aimed at conserving Christmas Island's biodiversity in the face of climate change.

Acknowledgements

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