

## The Hulu Cave $^{14}\text{C}$ record

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Of a plethora of research directions, one of Wally's first involved  $^{14}\text{C}$  [1]. Indeed, even in the focused field of  $^{14}\text{C}$  as applied to cave deposits, he started the field [2]. He also led the development of U/Th dating [3]. He then pursued and nurtured these research threads (among many others) for 6 decades plus. Thus, it was not a surprise to the senior author when, 3 weeks before his passing, the topic of discussion turned to  $^{14}\text{C}$  and U/Th dating at Hulu Cave, an effort that Wally supported whole-heartedly and helped to fund. Results of this work had been published only weeks earlier [4].

3 stalagmites from Hulu Cave are particularly suitable for  $^{14}\text{C}$  calibration as they have unusually low and apparently stable dead carbon fractions, equivalent to 470 y. 520 pairs of  $^{14}\text{C}$  and U/Th analyses yield a record of atmospheric  $^{14}\text{C}/^{12}\text{C}$  from 11 to 54 ky B.P. The older portion completes a precise calibration back to the limits of the  $^{14}\text{C}$  timescale.

Considering the full record, past atmospheric  $\Delta^{14}\text{C}$  levels are generally higher than pre-industrial values, with glacial  $\Delta^{14}\text{C}$  values up to +700 per mil (equivalent to  $^{14}\text{C}$  ages 5200 younger than U/Th ages) correlated with the Laschamp excursion and with Heinrich Stadial 4. Millennial-scale variability can generally be attributed to geomagnetic field changes, but some millennial-scale variations as well as a long diminution of  $\Delta^{14}\text{C}$  broadly associated with Termination I, can be attributed in part to marine carbon cycle changes associated with climate shifts.

[1] W.S. Broecker & J.L. Kulp. 1954. The radiocarbon method of age determination. *American Antiquity* 22 (1)11-22.

[2] W.S. Broecker & E.Z. Olson. 1959. C-14 dating of cave deposits. *Bull. Nat. Speleo. Soc.* 21 (Part I), 33-42.

[3] W.S. Broecker. 1963. A preliminary evaluation of uranium-series inequilibrium as a tool for absolute age measurement of marine carbonates. *JGR* 68 (9) 2817-2834

[4] H. Cheng et al. 2018. Atmospheric  $^{14}\text{C}/^{12}\text{C}$  changes during the last glacial period from Hulu Cave. *Science* 362, 1293-7.