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Speleothem organic biomarkers trace last millennium fire history at near-annual resolution in northwestern Australia

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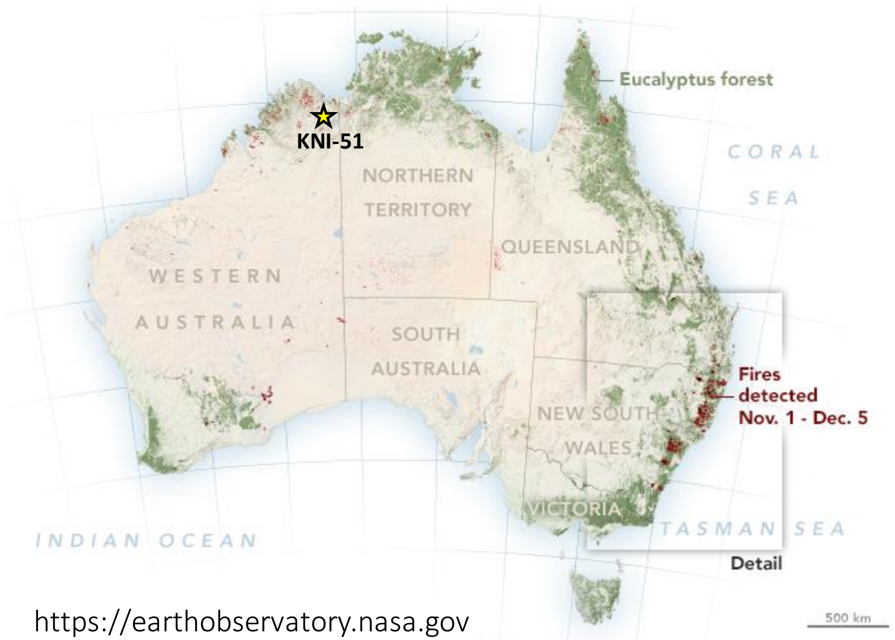
SUPPORTING MATERIAL

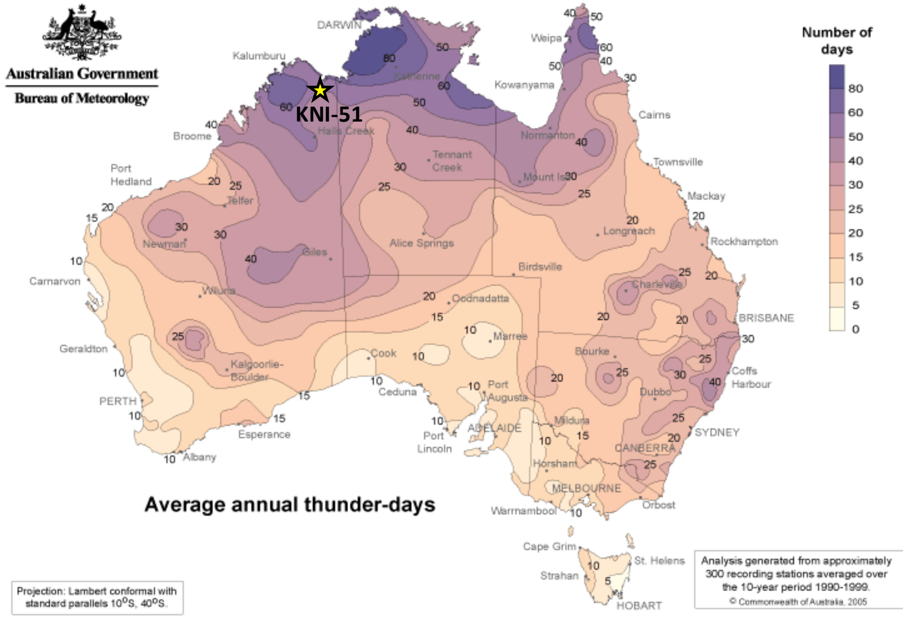
CLIMATE, FIRE, AND HUMANS AT CAVE KNI-51

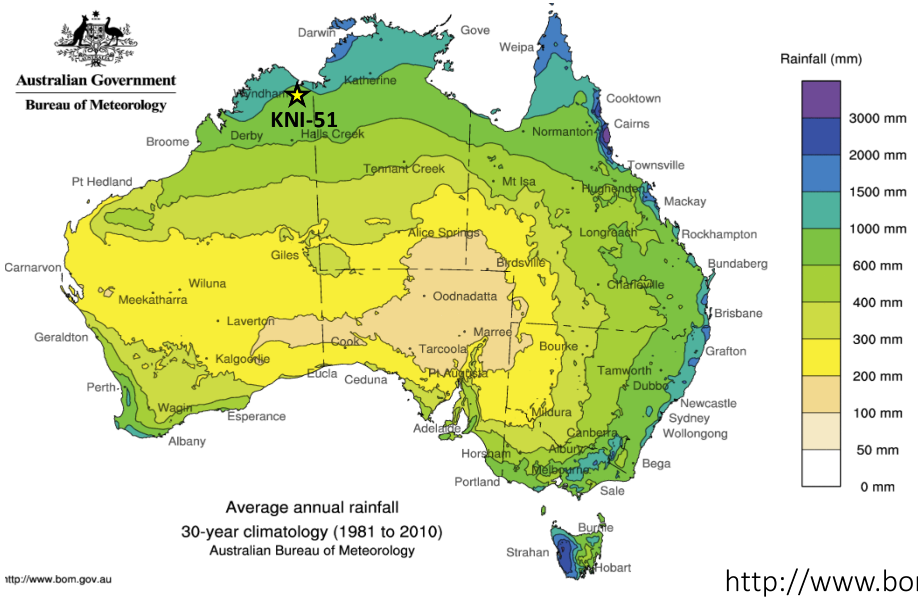
Cave KNI-51 is located in the Kimberley region of Northwestern Australia, a highly fire prone area where bushfires are common throughout the dry season, due to human activity including both cultural and management burns, and arson and, in the late dry season (Sep-Nov), lightning strikes.

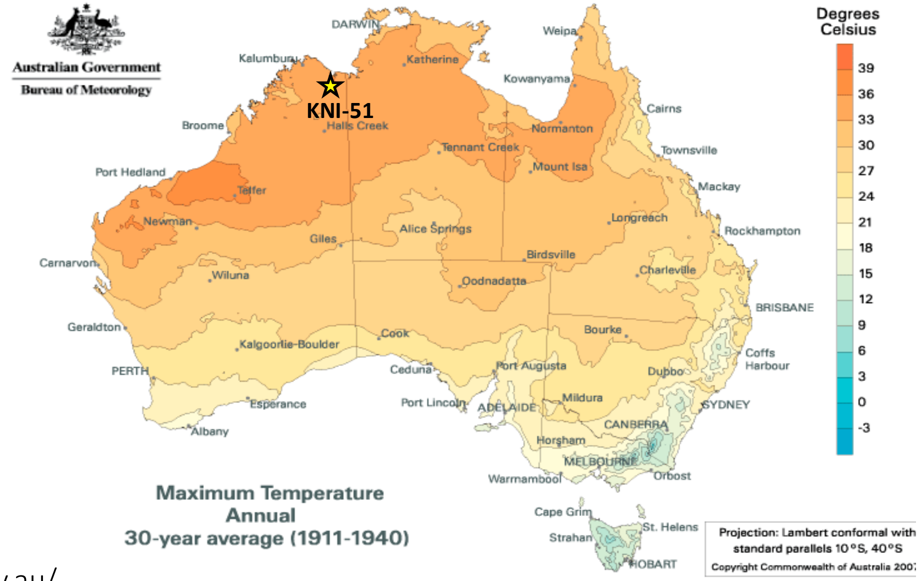
Drivers of fire activity in the northwest Australian tropics are closely tied to the tropical monsoon climate, but also to how humans manage fires and alter fuel dynamics. Burning by Australian Aboriginal peoples has played an important role in ecosystem dynamics for millennia, while the arrival to northwest Australia of European pastoralists and the associated displacement of Aboriginal peoples in the late 19th century profoundly changed the nature of fire in this region, although to what scale is still unclear.



https://earthobservatory.nasa.gov

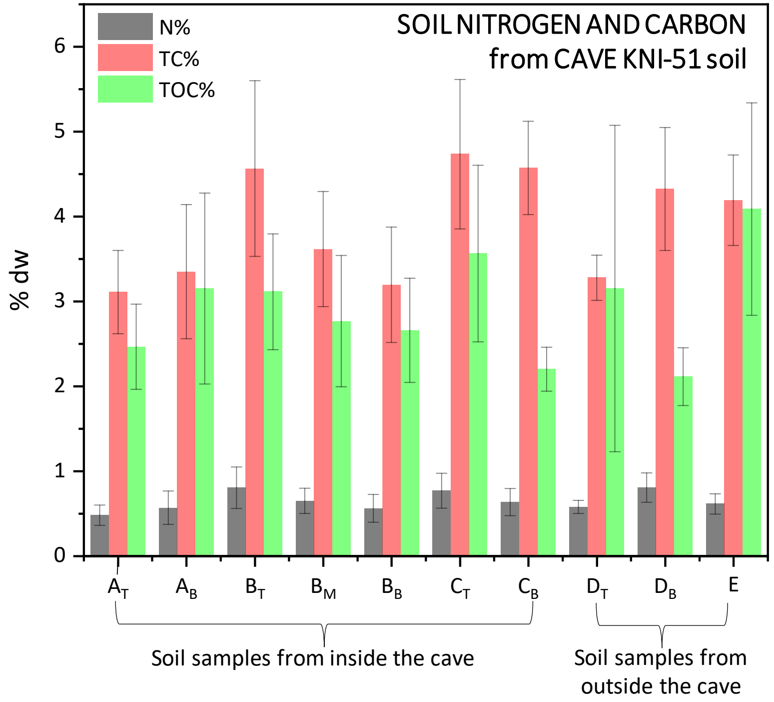






http://www.bom.gov.au/

SUITABILITY OF CAVE KNI-51 FOR PALEOFIRE RECONSTRUCTION FROM ORGANIC PROXIES



OUTSIDE THE CAVE

Cave KNI-51 is a **shallow cave** (~ 10 m deep) overlain by permeable and fractured **limestone**. **Soils are thin**, poorly developed and with **low organic carbon** content (2-4%).

The vegetation around cave KNI-51 is predominantly **eucalypt woodlands and mix woodlands/grasslands**, with some areas of **tussock grasslands**.

The area is **remote** (> 40 km from nearest town, 25 km from nearest paved road) and sparsely populated, limiting fossil fuel as possible source of hydrocarbons.

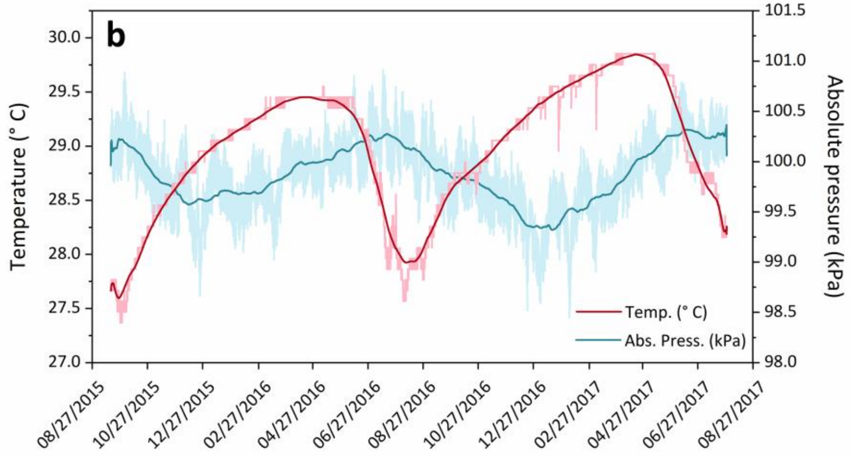
INSIDE THE CAVE

Temperatures during the wet season - when the majority of stalagmite growth occurs - **are stable** (29.7±0.2˚C). **Air exchange is minimal** and thus transport of aerosols into the stalagmite room is unlikely.

Residence time and reworking of proxies in soil thus are limited, as are possible sources of organic compounds to stalagmites other than cave dripping.

Therefore, observed concentrations are likely only deriving from fire activity, as proxies are produced by biomass burning and deposited onto overlying soil.

Cave pressure and temperature 2015-17

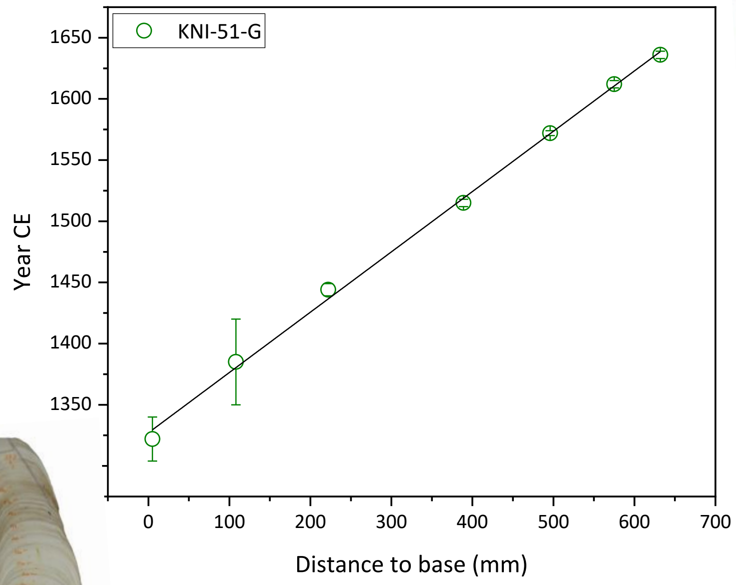


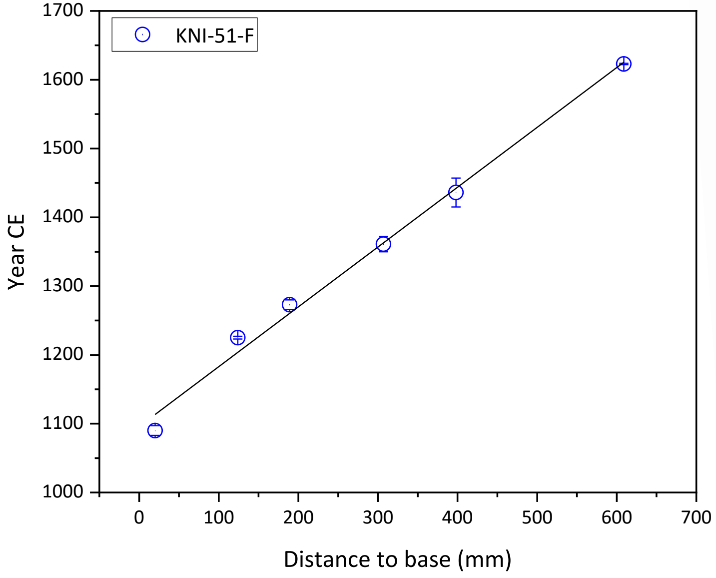
Argiriadis et al. (submitted)

SUITABILITY OF CAVE KNI-51 FOR PALEOFIRE RECONSTRUCTION FROM ORGANIC PROXIES

SPELEOTHEM GROWTH

Stalagmites at cave KNI-51 have a notably high and regular growth rate, up to **1-2 mm yr^{-1}**.
This allows achieving a **high resolution** paleofire reconstruction **despite the** relatively high **amount of sample** needed for retrieving trace organic compounds (~1 g).



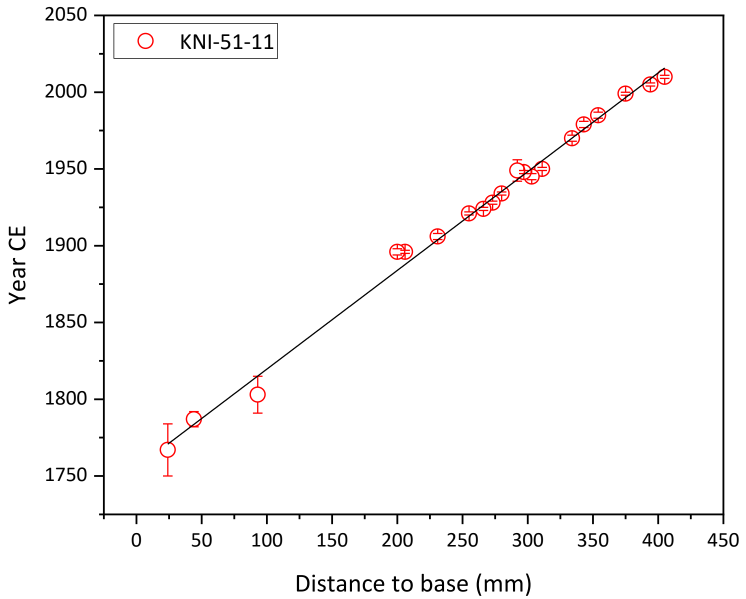


RADIOMETRIC DATING

Previous work on stalagmites from cave KNI-51 included dating through U-Th disequilibrium methods and yielded **high precision age models** (2 s.d. errors of ±1-2 yr over much of last century). The three stalagmites included in this work grew across the **last millennium:** <u>KNI-51-F</u> (CE ~1100-1620), <u>KNI-51-G</u> (CE ~1320-1640), and <u>KNI-51-11</u> (CE ~1750-2009).

CAVE FLOODING

Frequent flooding of the cave during the wet season causes mud layers to be included into stalagmite deposits.
The thickest mud layers in stalagmite **KNI-51-11** are associated with a **change in growth direction**, suggesting that the stalagmite shifted its position on its mud substrate during large flood events. Such a change in geometry complicates age-distance relationships between radiometric dates. This problem was limited through a **higher density of high-precision dates**. Growth direction changed several times during its history, each time in association with a thick layer of sediment.



Denniston et al. (2013, 2015)

Previous studies at cave KNI-51:

1. Denniston RF, Wyrwoll K-H, Polyak VJ, Brown JR, Asmerom Y, Wanamaker AD, LaPointe Z, Ellerbroek R, Barthelmes M, Cleary D, Cugley J, Woods D, Humphreys WF (2013) *A Stalagmite record of Holocene Indonesian–Australian summer monsoon variability from the Australian tropics*. Quat Sci Rev 78:155–168. https://doi.org/10.1016/J.QUASCIREV.2013.08.004

2. Denniston RF, Villarini G, Gonzales AN, Wyrwoll K-H, Polyak VJ, Ummenhofer CC, Lachniet MS, Wanamaker AD, Humphreys WF, Woods D, Cugley J (2015) *Extreme rainfall activity in the Australian tropics reflects changes in the El Niño/Southern Oscillation over the last two millennia*. Proc Natl Acad Sci 112:4576–4581. https://doi.org/10.1073/pnas.1422270112

3. Denniston RF, Ummenhofer CC, Wanamaker AD, Lachniet MS, Villarini G, Asmerom Y, Polyak VJ, Passaro KJ, Cugley J, Woods D, Humphreys WF (2016) *Expansion and Contraction of the Indo-Pacific Tropical Rain Belt over the Last Three Millennia*. Sci Rep 6:34485. https://doi.org/10.1038/srep34485

4. Denniston RF, Asmerom Y, Polyak VJ, Wanamaker AD, Ummenhofer CC, Humphreys WF, Cugley J, Woods D, Lucker SL (2017) *Short Communication: Decoupling of monsoon activity across the northern and southern Indo-Pacific during the Late Glacial*. Quat. Sci. Rev. 176:101-105. https://doi.org/10.1016/j.quascirev.2017.09.014

5. Argiriadis E, Denniston RF, Barbante C (2019) *Improved polycyclic aromatic hydrocarbons and n-alkanes determination in speleothems through cleanroom sample processing*. Anal Chem 91:7007–7011. https://doi.org/10.1021/acs.analchem.9b00767